

# THE ELECTRIC WAVE SPECTRUM IN POLICE SCIENCE

THE ELECTRIC WAVE SPECTRUM			
REGION	WAVE LENGTH (cm.)	SOURCE	APPLICATION
GAMMA RAYS ELECTRON RAYS	10 <sup>-10</sup>	SPONTANEOUS EMISSION BY RADIOACTIVE ATOMS	Investigative techniques for the detection of larceny and other crimes, using radioactive indicators to prelabel clue materials and a Geiger counter to detect radiations of the indicators  Gammagraphs—Deep penetration to detect hidden structural flaws in metal  Determination of the thickness of metals and depth of liquids in closed tanks by Penetron measurements  Electron microscopy of traces such as metals, dust, fibers, ink, semen, etc.  Electron diffraction studies of surface film
	10 <sup>-9</sup>		
	10 <sup>-8</sup>		
X-RAYS	10 <sup>-7</sup>	ORBITAL SHIFTS OF INNER SHELL ELECTRONS BY CATHODE RAY BOMBARDMENT	Analysis by x-ray diffraction to identify and compare substances  Radiography to examine internal structure as in suspected bombs and defective metal parts—Examination for hidden contraband such as guns—Identification of unknown dead—Fogging of film in spy cameras—Detecting fraudulent paintings—Soft x-ray examination and comparison of clue materials such as fabrics, paper, leather, jewelry, biological specimens, and gunshot powder marks
	10 <sup>-6</sup>		
ULTRAVIOLET	10 <sup>-5</sup>	VIBRATION OF INTERMEDIATE ELECTRONS	Detecting pre-labeled gasoline, ink, money, documents, etc.  Fluorescent examination of seminal and other stains, glass, gems, teeth, fingernails, hair, cosmetics, secret writing, erasures and obliterations, altered seals, laundry marks, fingerprints, pottery, statues, paintings  Spectroscopy and ultramicroscopy
	10 <sup>-4</sup>		
VISIBLE INFRARED	10 <sup>-4</sup>	VIBRATION OF VALENCE ELECTRONS	Visual examinations as of fingerprints, handwriting, documents, photography, microscopy, spectroscopy, refractometry, spectrophotometry, colorimetry  Photographic comparison of textiles, paints, stains, inks, etc.  Deciphering of burned and charred documents, erasures, invisible inks— Examination of the contents of sealed letters Thermometry—Spectrometry—Comparison of clue materials by molecular spectra  Supersensitive bolometer for detection at night of persons in open spaces Snooper scope for observations in darkness Communication devices for secret messages Photocell intrusion alarm
	10 <sup>-3</sup>	VIBRATION OF ATOMS AND MOLECULES	
	10 <sup>-2</sup>		



Radar detection devices and direction finders

Microwave receivers for detecting a beam reflected by an intruder

SHORT  
OSCILLATIONS

HIGH

ELECTRIC

SPARK

ANTENNA

CIRCUIT  
CAPACITANCE

ALTERNATING

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11/11

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of criminal evidence

10<sup>-1</sup>

1

10

10<sup>2</sup>

10<sup>3</sup>

10<sup>4</sup>

10<sup>5</sup>

MICRO  
WAVES

SHORT ELECTRIC

RADIO  
SHORT  
WAVES

STANDARD  
BROADCASTING

LONG ELECTRIC



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# **AN INTRODUCTION TO CRIMINALISTICS**

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AN INTRODUCTION TO **2**

# *Criminalistics*

*The Application of the Physical Sciences  
to the Detection of Crime*

Charles E. O'Hara & James W. Osterburg

MEMBERS OF THE STAFF, POLICE LABORATORY,  
NEW YORK CITY POLICE DEPARTMENT

THE MACMILLAN COMPANY : *NEW YORK*



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PRINTED IN THE UNITED STATES OF AMERICA

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*DEDICATION*

*To the many scientists in the fields of mathematics, physics, chemistry, biology, medicine, and psychology whose labors have built the foundations for the science of criminalistics.*



*I hear much of people's calling out to punish the guilty, but very few are concerned to clear the innocent.*    DANIEL DEFOE



# INTRODUCTION

In this century of change and progress, it should not be surprising to discover that law enforcement officers have taken great strides forward both in the effectiveness of their methods and in their ability to draw on other sciences for the improvement of their techniques. The impact of science on police work may be readily observed in the extensive employment of modern means of communication and transportation. The most striking change, however, will be found in the manner in which the police collect and examine physical evidence. This is a change that has had far-reaching effects not only in police departments but in the offices of district attorneys and in the courts of law.

Seen in the light of modern science, physical evidence attains an entirely new significance. It was the realization of this fact that led to the establishment of police laboratories in this country. The present state of scientific criminology is a tribute to the ceaseless struggle of police officials and police scientists over the last twenty years. Today it is a matter of accepted routine for the courts and law enforcement officers to seek the services of the police laboratory wherever a question concerning physical evidence arises. The scene of a crime is no longer looked upon simply as a base for questioning witnesses. It may also be considered as a field laboratory site where traces of clue material can be discovered and made to give eloquent testimony at the trial.

The development of techniques and equipment, however, may not in themselves be considered as tributaries to progress unless they are properly employed. It is for this reason that it is gratifying to find that the point of view of the modern police officer has been modified to give him a correct perspective. Law enforcement officials today employ police science with equal zeal for the establishment of innocence as for the discovery of guilt. It is in this spirit that the present work has been written. The authors have endeavored here to give a clear presentation of the practical procedures of scientific criminology together with their theoretical foundations. A textbook of this nature will have an appeal to all those concerned with the processes of law enforcement and the treatment of evidence — criminologists, lawyers, and judges as well as police officers.

GEORGE P. MONAGHAN,  
*Police Commissioner, City of New York*

January 28, 1952.



# FOREWORD

The expanding functions of the modern police department have resulted in an ever increasing complexity in its operations. In the last thirty years separate branches have grown to considerable size within the framework of the police organization. Patrol, investigation, traffic, communications, identification, juvenile crime prevention, emergency service, and other units constitute separate areas of specialization. With this growth has come a demand for new skills and directed training. Indeed, specialization is rapidly becoming mandatory in any efficiently managed police department.

The police laboratory is, perhaps, the latest of these branches to achieve recognition as an essential part of the law enforcement body. Its youth and rapid development have not permitted it to assume as yet a well defined form. The pattern and scope of the forensic laboratory will be found to vary widely in different cities and states. In this book the authors have endeavored to explain the principles which underlie the work of all police laboratories and to describe the methods which their experience and research have found most effective.

Of the many contributions which the authors have made in this book the most important, I believe, is the concept of an integrated, scientific approach to crime detection. The individual detective must consider himself a member of a team which approaches the problem presented by a crime with a rationalized plan of attack. The close association of the laboratory scientist with the man in the field was proved in World War II to be an invaluable combination in military operations. Similarly, the cooperative recognition and understanding of problems and resources forms the basis of an effective alliance in detective work.

Confronted with the wide range of subject matter treated from a specialized point of view, the reader will, I believe, conclude that scientific crime detection is a full-time career which must be based on a thorough academic preparation in the sciences. It is, in short, a profession providing a service which is essential to society in its efforts toward the suppression and detection of crime and the protection of the innocent.

ARTHUR W. WALLANDER,  
*Police Commissioner, City of New York,*  
*September, 1945–February, 1949*

December, 1948.



## PREFACE

The continued high rate of crime in this country has brought into sharp focus the police methods which are in current practice. A critical appraisal has revealed a number of disturbing inadequacies in the police mind and the techniques which it employs. A certain degree of conservatism is to be expected in a profession which dedicates itself to the preservation of the *status quo*; but we have witnessed that, while there has been in recent years a tremendous demonstration of the effectiveness of applied science in warfare, during the same period the police forces of the nation have come forward with nothing more revolutionary than the increased use of two-way radio. We may therefore safely question the effectiveness of the law enforcement mind.

A particular example of this intellectual lethargy is offered by the special field of scientific crime detection. A comparison of the techniques applied to the examination of physical evidence in 1938 with those of 1948 will reveal the fact that practically no new methods have been developed during the past ten years. Refinements of technique have been suggested in this period, but the essential methodology and instrumentation have remained unchanged. This situation has existed during a period of unparalleled development in other sciences. Another significant fact is the number of police laboratories which have been in existence over this period. There has been a remarkably small increase in this number. It may be offered in reply that these statistics are evidence of the failure of science in police work; that the tried and true methods have been applied effectively, and that, had the police laboratory been successful, its growth would have been fostered. To this we can only add the paraphrase: It is not that police science has been tried and found wanting — it is rather that it has been found difficult and left untried.

With the exception of a few large cities and states, scientific criminal investigation has not been applied on a scale suited to even the barest needs. In many sections of the country it is literally true that “you can get away with murder.” The fresh physical evidence of bloodstains, fingerprints, footprints, and other clues, quickly becomes worthless in the absence of trained police personnel. This is particularly unfortunate in rural areas, since police science is decidedly more effective where the number of suspects is limited and the presence of witnesses is less probable. The misfortune for society lies not so much in the possibility that the criminal may go unpunished as in the danger that an innocent person may be wrongly accused.



This failure to apply science on a wide scale to criminal investigation can be attributed to many causes. Chief among these, perhaps, is the inability of civil service to attract competent personnel. Instead of employing men who are trained in science, the practice in many communities has been to submit the clue materials to the fumbling ministrations of a local detective who may be a hobbyist or an amateur in laboratory methods. There are only four or five cities in which formal examinations are conducted to obtain qualified scientists for police work.

Another explanation of the current indifference to police science and a reason also for the failure to attract competent workers to the field is the absence of any systematic literature devoted to the subject. In the English-speaking countries particularly, the most talented contributors to police science have considered the work an avocation rather than the major interest of their endeavors. Their contributions have usually been by-products of their research in other studies and not the direct outcome of a planned attack on the problems of criminalistics. The result of this approach has been a conglomeration of material ranging in quality from scholarly theses to mere tricks and recipes of doubtful worth.

The student entering the field of scientific crime detection finds himself confronted by an odd assortment of texts. Most of these are popularizations which explain away the difficulties of subject matter in terms of facile analogies. The more serious works are optimistically written with a view to making a scientist out of a detective; but here again, the road to a true understanding of the principles of criminalistics is blocked by the necessity for oversimplification. A few texts meet squarely the major problem: To make a detective out of a science student, i.e., to develop from the scientist the scientific investigator of crime, by showing how the principles and techniques which he has studied can be applied to the peculiar problems of examining clue materials.

This confusion is appropriately represented in the names which are employed to designate this branch of knowledge. The terms *police science*, *scientific criminology*, *scientific criminal investigation* are applicable also to police administration and methods of detection in general. *Forensic chemistry* and *forensic science* express too little to be useful. The authors have decided, for the purposes of the present text, to use the name *criminalistics* in referring to the work of the police laboratory. This is not entirely a neologism. The words *Kriminalistik*, *criminalistique*, and *criminalistica* are in common use in continental Europe, where greater care is given to precision of terminology. We shall define *criminalistics* as that science which applies the physical sciences in the investigation of crimes. We have not restricted ourselves merely to this term but have used the others loosely as synonyms in order to avoid any formal rigidity in the writing. One objection which may be raised against the use of this term is that the words *criminalistic* and *criminalistical* are to be found with a different definition in the unabridged dictionaries. The words are, however, rarely used and may be considered obsolete. The advantages, moreover, easily overcome this objection. First, we are provided with a single word to designate the science. Second, the



danger of ambiguity is avoided. Third, a means of distinctively classifying the literature of the subject is provided, thereby eliminating the difficulties which the student now encounters in searching for library references. Fourth, a word comparable to that used in other languages facilitates the study for the foreign student.

The lack of organization in forensic science is attributable in part to the nature of the work. Criminalistics must depend for its development largely on the principles and data of the major physical sciences — chemistry, physics, and biology. It is in that respect a parasitical branch of knowledge. It does not attain to the dignity of a science in itself until it adapts to its own use and organizes for its own specific purpose the findings of other sciences. Drawing its techniques from such diverse sources, police science does not lend itself to the ready classification which the work of the medical examiner enjoys.

Another reason for the present state of affairs lies in the varied backgrounds of the contributors, most of whom have had little experience as practicing detectives or police officers and hence have cloudy views of the problems which face the police. The techniques which an investigator will find effective in the field are frequently altogether different from the elegant methods developed in the laboratory by men who have no experience in practical detective work.

To attain the scientific order which is desirable in a work of this nature, we have arranged the subject matter according to the branch of science in which it falls. The applicable principles and instruments of each field are described and then applied to definite problems which deal with clue materials. In this way the power of the theories and methods is stressed, and their extension to further problems is suggested. Equations have been derived wherever their importance justifies the space. Many of these equations recur in various chapters. Certain relations in optics, for example, will be found in chapters on photography, microscopy, x-ray diffraction, and the electron microscope.

It is intended that this work shall serve several purposes. One of the principal aims is to offer a textbook for college students who wish to study for careers in police science. To this end the material has been arranged in textbook form and written in a style suitable to the needs of the student. Most of the chapters have been provided with exercises to test the reader's mastery of the subject matter and to assist him in practical application of the techniques which are described.

Detectives, patrolmen, private investigators, and others whose duties include the collecting and evaluating of clue materials will find many sections here which will guide them in their work, suggesting the value of the various kinds of physical evidence and prescribing the procedures necessary for their proper care. It is hoped also that jurists and lawyers will find the work useful in judging the worth and reliability of expert testimony in courts. For the practicing police scientist we believe that this book may serve as a reference work for the methods which are needed in this field, and that it will be suggestive of many techniques with which he is not acquainted.

The treatment of the subject matter in a text of this nature presents a



problem to which we have found no happy solution. Since the book is not single in its purpose but is designed for a varied audience, it is not possible to maintain an unvarying point of view. The wide variety of subjects which are treated necessitates inclusion of matters which are of high-school simplicity with those which approach the graduate-school level of difficulty. The table of contents will be found to include such diverse topics as the micrometer caliper, powdering a fingerprint, x-ray diffraction, and spectrophotometry. We can see no way out of this difficulty if this work is to maintain its character as a source book for criminalistic techniques.

In the selection and treatment of this material the authors have drawn constantly on their experience in the laboratory and in the field. Having engaged in or observed several thousand cases, many of which were of major importance, they have been able to estimate the frequency with which various laboratory techniques are applied. Case histories, however, have been avoided completely, partly because they would add excessively to the number of pages but mainly because the typical anecdote contributes little of value to the theory or practice of police science, and even less to the art of the detective story. In selecting the subject material a number of important omissions were necessary. Notable among these are the subjects of toxicology, handwriting comparison, firearms identification, and lie detection. A study of these matters would have required another volume more than half the size of the present one. There are, moreover, a number of texts on these subjects already in existence.

Much of the subject matter has been approached from a different point of view. The literature of police science has been greatly influenced by the medical examiner. In consequence, it deals predominantly with serious crimes of violence — homicide, rape, poisoning, and so forth. This preoccupation with crimes against the person has led to a neglect in many texts of the large number of offenses which may involve physical evidence unrelated to medical science. Solution of gambling, burglary, theft, and similar crimes comprises the great mass of the detective's work. The examination of evidence in these cases has, however, received meager treatment in the literature. The authors have sought to correct this deficiency by describing laboratory procedures which are applicable to a wide variety of crimes.

A notable failing in the literature of forensic science is the meager treatment of the subject of motor vehicle homicides. When it is considered that there are approximately 35,000 motor vehicle deaths each year as compared with 6,000 homicides from all other sources, the literature appears inordinately weighted on the side of the more spectacular methods of homicide. This bias is due in part, perhaps, to the greater interest and the intellectual challenge which mysterious deaths offer the forensic scientist. A more important cause of this indifference is the fact that the negligent driver is ordinarily innocent of an criminal intent; he is not a habitual criminal in the legal sense. The respectability of the defendant tends to mitigate the gravity of the crime. It may be said in reply, however, that the magnitude of an offense derives primarily from the character of the injured person. Whereas in the usual homicide of violence



the deceased is often a person of questionable reputation, the hit-and-run victim is in most cases an innocent and useful member of society, frequently a child.

Because we consider the negligent driver one of the most dangerous of criminals, we have devoted a commensurate space to the work of the laboratory in the investigation of motor vehicle accidents. The chapters treating this topic have been arranged in sequence to provide an independent unit for specialists in this field.

We have endeavored wherever possible to stress the importance of field work. Quite frequently the important critical work in a case involving physical evidence is performed at the scene of the crime and not at the laboratory. The services of the scientific investigator are needed primarily at the scene, where his experienced and critical mind can judge the worth of the evidentiary traces and determine the methods by which adequate samples can best be collected and preserved. The analysis at the laboratory is often a routine affair which may be entrusted to an ordinary technician. The technique, for example, of operating a spectrograph can be mastered quite readily by a laboratory assistant. The knowledge, however, which leads to the discovery, correct evaluation of the clue materials, and proper care of the traces found in connection with the crime must be derived from thorough training and experience.

There is at present an unfortunate tendency in this country to retain the criminalistician within the walls of his laboratory and to surrender the important task of selecting and sampling the evidence to a detective to whom the case has been assigned. This indifference to the first and essential steps of a scientific investigation is due in great part to necessity. Few cities or counties possess a mobile laboratory unit. Their procedure in regard to physical evidence is to ignore it in minor cases and, where the crime is more serious, to send the evidence to a state or federal laboratory for analysis. The great distances separating the site of the crime from the laboratory forbid a visit from the trained analyst. Thus it has become customary to consider the police scientist as the distant recipient of the physical clues rather than the active participant in their discovery. The evils of this system are apparent. They are aggravated by the fact that the convenience and economy of such an arrangement help to sustain the tradition. The authors feel that there is a pressing need for a reform — that each large community should maintain a police laboratory of appropriate size.

The experience of the authors as testifying experts has led them to provide an adequate background of theory in each chapter. It must be remembered that the police scientist will be called upon to defend his conclusions in his court testimony, and that opposing counsel will be permitted to ask him questions concerning the branch of science in which he is testifying. The interrogation will frequently take the form of a classroom quiz period. Often there will be a manifestly unfair advantage on the side of counsel. If, for example, the expert is testifying about his microscopic findings, he will be considered fair game for questions dealing with resolving power, diaphragms, and numerical aperture. The questioning is often illogical and irrelevant. A biologist may use a microscope effectively for many years without an adequate knowledge of the



laws of optics. A photographer can attain a high degree of technical proficiency without knowing much about the chemistry of development, yet he will lose some standing in the eyes of the jury if the elementary theory is not at his fingertips. This is how the game is played; hence we have endeavored to equip the future expert to withstand a rigorous cross-examination in his field. This is not, of course, the sole or even the major reason for stressing the theory. The intelligent employment of the methods of science must always be based on a true understanding of its principles.

The qualifications which should be required of a police scientist are difficult to state precisely. There is a tendency among civil service commissions to stress in their requirements for a forensic scientist the importance of a Ph.D. degree, or other specialized graduate training. This is perhaps due to a misunderstanding of the work of the police laboratory. The criminalistician should endeavor to acquire breadth as well as depth in his scientific education. The person proficient in chemistry alone will find himself inadequate to deal with elementary problems of a physical or biological nature. The work of criminalistics is characterized by the great variety of relatively elementary subjects which must be mastered. At the scene of a crime the police scientist is essentially a diagnostician. Confronted with the physical evidence of the crime he must indicate the significance of these clues and outline the procedures whereby their full value can be realized. An authoritative understanding of a limited phase of police science will not take the place of a rounded knowledge of the many resources of that science.

In conclusion we should like to stress the fact that we have not intended in writing this text merely to place in the hands of the prosecution an additional means of increasing its efficiency. It is more important that we provide a shield for the innocent defendant than a weapon for the prosecution. Although physical methods of the "third degree" have long since become obsolete, equally brutal techniques of a psychological third degree are frequently employed in the interrogation of suspects. It is hoped that the science of criminalistics will offer a more civilized approach to the problem of obtaining and evaluating evidence.



## *ACKNOWLEDGMENTS*

The authors are deeply indebted to many sources. We wish to express our gratitude to Police Commissioner William P. O'Brien and former Commissioner Arthur W. Wallander for their encouragement and kind permission to use the resources of the New York Police Laboratory in preparing this work. To Professor Louis Sattler of Brooklyn College we are greatly indebted for his unfailing generosity in reading and correcting a considerable portion of the text, and for his innumerable suggestions of technique and treatment. Dr. Alexander S. Wiener and Mrs. Eve Sonn Gordon of the Chief Medical Examiner's Office of New York City read the chapter on blood. Professor M. D. Hassialis of Columbia University read the material on microscopy and photography. Dr. Clarence E. Ireland of Staley Products, Inc. reviewed the parts devoted to physical measurements, physical examinations, and spectrophotometry. Professor I. Fankuchen of Brooklyn Polytechnic Institute offered many helpful suggestions in the treatment of x-ray diffraction. Professor William L. Parker of the same institution reviewed the spectroscopy chapter. Professor Harry A. Charipper of New York University corrected the chapter on semen examinations. Dr. M. C. Banca of Radio Corporation of America read the section on electron microscopy. The chapters devoted to treatment of data and criminalistic proof were reviewed by Professor Alexander Calandra of Washington University. Dr. Joseph Schultz, formerly director of research for the New York Chemical and Quinine Company, read the material on narcotics. Professor R. N. Harger of the University of Indiana reviewed the chapter on blood-alcohol determinations. Mr. J. P. Thompson of the General Electric Company read the chapter on spectrophotometry. Mr. J. S. Baker, Director of Research at Northwestern University Traffic Institute, read and corrected the chapter on the determination of automobile speeds from skid marks.

Of the many others who cooperated in this work, special mention should be made of Mr. Frank D. Doyle, Secretary of the Police Department, Chief Inspector August W. Flath, the late Chief Inspectors, Martin J. Brown and John J. O'Connell, Chief of Detectives William T. Whalen, Act. Dep. Chief Insp. Michael E. J. Ledden, Act. Capt. Edward F. Fagan, Act. Capt. Daniel C. Murphy, Lieut. Edward A. Palmer, and our colleagues in the laboratory of the New York City Police Department. Mr. Mathias J. Schuler, and Dr. Allison Maggiolo of Columbia University also rendered valuable assistance.

To Mr. Alexander Thomas of the New York Police Laboratory we are



especially grateful for the many drawings which he prepared for this text and the constant zeal which he brought to the task under difficult conditions. Mrs. Helen Herbert McKenna and Mr. John P. Weiss rendered invaluable assistance in the tedious and exacting work of preparing the manuscript.

The incomparable library facilities of New York were at our disposal during the writing of this text. Miss Ruth D. Grotheer of the Queens Borough Public Library and Miss Rebecca Rankin of the Municipal Reference Library were particularly helpful in making available the many books, journals, and microfilms which we found it necessary to consult. In this connection the Misses S. Moore, E. Terek, M. Pierri, A. D. Perillo, M. Wood, of the Queens Borough Public Library also assisted in various ways.

The authors wish to acknowledge gratefully, the cooperation and assistance of the following individuals, industrial concerns, and scientific societies for furnishing illustrative materials or for permitting the use of textual matter from their publications:

Dr. C. W. Muehlberger, Dr. F. L. Kozelka, Mrs. Rose Brenner, Mr. Jerome Bates, Miss Frances Reichart, Mr. Robert S. Fish of the Alfred Bicknell Associates, Mr. C. J. Woods of the North American Philips Co., Lieut. R. F. Borkenstein of the Indiana State Police, the American Chemical Society, the American Transit Association, the Bausch and Lomb Optical Co., the General Electric Co., the Jarrell-Ash Co., the National Safety Council, the North American Philips Co., the Radio Corporation of America, and the Dow Chemical Co.; the Funk and Wagnalls Co. for permission to quote from the chapter on Questioned Documents in their publication, *Modern Criminal Investigation*, by Söderman and O'Connell; the McGraw-Hill Book Co. for permission to reprint the color plate from their publication, *Inorganic Analysis*, by Cady; the Reinhold Publishing Corp. for permission to use data appearing in their publication, *Noxious Gases*, 2nd ed., an American Chemical Society Monograph by Henderson and Haggard; Mr. A. D. Osborn for permission to quote from the book *Questioned Documents* by the late A. S. Osborn; the John D. Lucas Publishing Co. for permission to quote from their publication, *Molding and Casting*, by C. D. Clarke. The Journal of Criminal Law and Criminology deserves special mention. The authors have drawn freely upon the articles which have been published in this journal.



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# PART A

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## THE LABORATORY IN GENERAL







# *CHAPTER I*

## *THE POLICE LABORATORY*

### **1. PURPOSE**

The function of the laboratory in police work is the scientific examination of physical evidence. Usually the purpose of this examination is to determine the manner in which a crime was committed, to connect a suspect with the crime, or to aid in establishing the identity of the criminal. Naturally, the activities of the laboratory are not rigidly confined to these objectives, but may include many other tasks which the manifold duties of police work entail. In the subsequent description of the laboratory, many of these activities will be brought out and the full scope of the laboratory will be more clearly outlined.

The examination of evidence is usually done at the laboratory. For example, a detective trying to establish the identity of an abandoned baby may have as his only clue the clothing in which the baby was dressed. He submits this evidence to the laboratory and requests an examination for laundry marks and other indications of the clothing's ownership. Another example is an arrest for an illegal sale of whiskey. In this case, it is necessary to establish the fact that the beverage sold is whiskey within the meaning of the law. The officer making the arrest submits a sample to the laboratory and asks for a chemical analysis to determine the nature of the alcohol and the alcoholic content of the alleged whiskey.

Frequently, however, the laboratory investigator must visit the scene of a crime for the purpose of a general examination of the physical surroundings to discover such traces as fingerprints, footprints, bloodstains, hair, fibers, matches, bullets, shells, dust, and other indications which may point to the perpetrator. For this work means must be provided so that the necessary equipment can be brought to the scene.

In order that a laboratory may be utilized to the fullest advantage by a police department, it is necessary that the personnel of the department be sufficiently well instructed in the elements of criminalistics to enable them to appreciate the value of the contribution of the laboratory in criminal investigations. Training schools for detectives and recruits should therefore include in their curricula an elementary course in scientific criminal investigation. The importance of pre-



serving undisturbed the evidence at the scene of a crime must be constantly stressed. One of the most frequent causes of complaint on the part of police scientists is the failure to safeguard the scene before their arrival. All too frequently, the tire tracks which might have been available as evidence have been rendered worthless by the thoughtless and careless traffic of persons who have arrived at the scene before the laboratory investigators. In cases of homicide it is often impossible to obtain fingerprints without at the same time including those of persons who appeared at the scene, but who are not associated with the crime.

The personnel of a police department should be impressed, too, with the importance of summoning the laboratory to the scene of a crime as soon as possible. To preclude negligence in this matter regulations should require the services of the laboratory at the scene of all homicides and other crimes of a serious nature when the solution is not obvious. This precaution insures also the proper sampling of the clue materials that may be present. The great importance of this may be realized from the dictum of the chemist that an analysis can be no better than the submitted sample. Since this is the case, it is evident that only trained scientists should be entrusted to collect the material to be used as evidence.

## 2. THE PLAN OF A POLICE LABORATORY

Since the function of the police laboratory is to make chemical analyses and physical examinations, and because these terms are so comprehensive, there are almost no limits to the elaborateness with which the laboratory may be equipped if it is to employ all the techniques which modern science has provided to convert mere clues into scientific evidence. Although the size of a police laboratory will vary with the population and character of the community which it is intended to serve, the general plan will usually include the following, either separate or combined:

- (a) A receiving room or desk where the evidence is received
- (b) An evidence room where the evidence is always stored except when it is being examined. Naturally, no one but members of the laboratory should be permitted to enter this room. Records may also be kept in this room.
- (c) A chemical laboratory
- (d) A fingerprint room — including facilities for developing prints with powder, iodine, and silver nitrate. Etching and casting equipment may also be used in this room.
- (e) A work room for repairing and building equipment
- (f) A photographic studio
- (g) A photographic darkroom for processing photographic materials
- (h) A room for physical tests and comparisons, including handwriting, ballistics, and microscopical examinations
- (i) An x-ray room which, of course, should be lead lined. Equipment for ultraviolet examinations may also be included in this room.
- (j) A room for spectrographic analyses



- (k) An office where the laboratory personnel may be consulted and where the director of the laboratory may conduct his affairs
- (l) A stockroom

A laboratory serving a small community would find two or three rooms sufficient for the functions indicated in the above list. Figure 1 on page 10 illustrates the plan of a laboratory suitable for a large city or state.

### 3. LABORATORY PROCEDURE

Because of the importance of preserving the continuity of possession of evidence, great care must be exercised at the laboratory in the procedure observed in delivering, receiving, and returning evidence. A minimum number of persons should be permitted to handle the evidence. Indiscriminate use of messengers should by all means be avoided. The procedure that should be used is included in the following steps:

(a) The detective in charge of the case, or the arresting officer will bring the evidence to the laboratory, together with a typewritten request for an examination. This application should include the following information:

1. Precinct and Arrest Number
2. Officer's Name, Shield Number, and Command
3. Defendant's Name and Address
4. Crime or Charge
5. Details of Crime
6. Place, Date, and Time of Occurrence
7. Name and Address of Injured Party or Deceased
8. Complainant
9. Date of Arrest
10. Description of Evidence and Probable Nature of Sample
11. Kind and Purpose of Examination Desired

(b) The receiving clerk will require the detective to have all articles of evidence properly sealed and labeled with identifying marks or signature. He will then enter the above information in a receiving book. All entries of evidence will be made chronologically in the receiving book and consecutively numbered. The number will be inscribed on the wrapper in which the article of evidence is received. A receiving sheet will then be filled out. This will contain in addition to the information on the request form, the following data:

1. Laboratory Number
2. Name of Person Delivering the Evidence
3. Date and Time of Receipt of Evidence
4. Officer Receiving Evidence
5. The Amount, Kind, and Description of Articles or Substance
6. How Packed



7. How Sealed
8. Identification Marks
9. Nature of Examination or Analysis

(c) The article of evidence is placed in the evidence room. The evidence room should be lined with shelves assigned appropriately to the various police precincts or divisions from which cases are received.

(d) A member of the laboratory staff is assigned to the case and is then permitted to remove the object from the evidence room. On completion of the examination or analysis, he will prepare a report of his findings for the arresting officer or detective in charge of the case. The report will be placed with the evidence in the evidence room.

(e) The arresting officer or detective in charge of the case will be notified to report to the laboratory and remove the evidence. He will sign the receiving book on receipt of his evidence.

(f) In cases where the members of the laboratory go to the scene of a crime and bring back the evidence themselves, a similar procedure should be followed.

#### 4. THE PERSONNEL OF A POLICE LABORATORY

The number of persons included in the staff of a laboratory will vary with the size of the laboratory. The director of the laboratory should have a broad scientific background, including graduate work, as well as some experience in detective work. He should be able to decide whether the laboratory can be of assistance in a particular case. Where the laboratory is large enough to conduct research, the director should be capable of suggesting lines of inquiry, assigning problems, and guiding the research.

In this country at least two police agencies have held nationwide examinations for positions that might be termed Director of the Laboratory. One examination,\* which demanded as part of the eligibility requirements three years' experience in a crime laboratory, consisted of an eight-hour practical laboratory test (35 per cent), a four-and-one-half-hour written examination (35 per cent) and an oral interview (30 per cent); the other† consisted of a written examination of four hours (60 per cent) and a qualifications appraisal based on the candidate's education and experience (40 per cent). These examinations were quite different in scope and they probably represent the limits between which suitable examinations can be constructed. It would be unfortunate to continue with the limited viewpoint of the examiners by insisting that only a chemist is capable of being the director of a police laboratory. Certainly, in laboratories of large cities or states, a physicist is equally qualified.

A clerk-stenographer should be assigned to the laboratory. He will receive and release evidence, care for the files, answer the telephone, and type the laboratory reports.

\* For Los Angeles County.

† For The State of Minnesota.



The members of the laboratory may, in some cases, be selected from among the members of the force (detectives or patrolmen). A college degree with a major in science is, of course, a prerequisite. Members of the force who are candidates for the laboratory should be selected by special examination prepared by the director. In order to provide a proper background of field work, a member of the force should be required to have completed about one year of police work. After selection, the candidate should be assigned for a few months to a detective squad, so that he may acquire a good understanding of the detective's problems, and gain experience in testifying in court.

If, as will frequently be the case, it is necessary to employ individuals directly from civilian life, the general procedure of civil service examinations or appointment by the police commissioner or other authority will probably prevail. In these cases the director of the laboratory should, of course, be consulted regarding the duties of the position, the requirements that should be set, the type of questions and examination which should be given, and any other suggestions that he may have regarding filling the position should be sought.

Among the laboratory personnel one of the most important members is the chemist. It will be found that a large number of laboratory cases require chemical analyses, some of which may be quite difficult. The chemist should, if possible, have done some graduate work in chemistry. This is desirable because expert testimony, in important cases, may be challenged and countered with experts for the defendant. A chemist who has not gone beyond the first courses will sometimes find himself out of his depth among more thoroughly trained experts.

A physicist should be included in the staff, although in a small laboratory the chemist may easily serve in both capacities because of the elementary nature of most of the physical problems which occur. Firearms identification, x-ray examinations, scientific photography, and photomicrography offer the most common opportunities for a physicist in a crime laboratory.

The examination of fiber, hair, wood, plants, and similar materials requires the services of a biologist with good knowledge of botany. The biologist should undertake a thorough study of common plants and soil in the local area. It will be found occasionally that a criminal will have adhering to some part of his clothing, seeds, soil, pollen, or some other trace which may associate him with the scene of the crime.

Next to chemical analyses in frequency are cases of questioned documents involving handwriting and typewriting comparisons, detection of forgeries, and restoration of obliterated writing. In a large laboratory one man may be required to devote his time to this study exclusively. A fair scientific background with a major in chemistry is a good starting point in beginning this study. Months of experience, however, are needed to achieve the status of expert.

Apprentices should be assigned to the elementary, routine work of the laboratory. A considerable amount of ordinary photographic work will be necessary. This work, together with the care of photographic solutions and equipment, should be performed by an apprentice. Where a member of the laboratory



does not desire to conduct research work and is without special qualifications, he should be assigned to this and other routine work permanently. In this manner it may be possible to allocate the work on the basis of competence and experience so that the most qualified members of the group will be devoting their time to research problems and not doing the laboratory chores which all too frequently are added to their professional burdens.

## 5. WORKING CONDITIONS

In a large city, the number of men assigned to the laboratory should be sufficient to enable the laboratory to remain open at all times — day and night, Sundays and holidays. Certain members of the staff should be assigned exclusively to day work; for example, the handwriting expert should maintain regular office hours, since detectives and investigators from outside agencies usually wish to consult with him concerning their cases. Similarly, a chemist should be present during the day because liquors, narcotics, and other evidence requiring chemical examination are usually submitted during the daytime. In addition, two investigators should be in readiness to respond to the scene of a crime when so requested by the commanding officer in charge of the investigation. If the volume of work is large, it is also desirable to have one or two men assigned to deal with evidence submitted for fingerprint examinations, indented writings, and other simple, routine processing; these men also serve as a reserve team of scientific investigators if the other field men are out on an investigation.

The importance of maintaining laboratory service during the night should be fairly evident. The value of foot impressions, fingerprints, stains, and other perishable clues may be irretrievably lost if there is a delay of ten or fifteen hours before the examination. Half of the battle in the work of blood grouping lies in obtaining a fresh sample, if it is available. A skeleton staff, then, of two persons should be on duty from about five in the afternoon until nine the next morning. They will respond to all calls from the scene of a crime; receive evidence at the laboratory, when present; work on cases previously submitted; and, if possible, pursue any research projects to which they may be assigned.

## 6. RESEARCH

The function of a police laboratory is not fulfilled merely by routine application of tried and true methods to routine cases. A constant search for new methods and techniques should be maintained. A difficult case should be looked upon as a challenge to be met by the improvement of technique or the widening of theoretical knowledge. The spirit of research is the source of progress in any laboratory, and it will be found that the police laboratory is especially fertile in research problems (Chap. 48). It should be a rule of a laboratory that qualified persons are required to conduct research in some field designated by the director or chosen by the individual with his consent.

Fixed duties of a routine nature should also be assigned to members of the staff. It is necessary for reference purposes to maintain a collection of inks, auto



lenses, rope and cord samples, textiles, tire sections, hair slides, paper, type-writing specimens, and other objects. The establishment and maintenance of each file should be the responsibility of one man.

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## CHAPTER 2

# LABORATORY EQUIPMENT

### 1. SIZE OF LABORATORY

The size of a police laboratory and the extent to which it is equipped naturally depend upon the size of the community which it serves and the crime conditions in that area. The size of the community is considered here with reference to both population and area. In some states the laboratory serves the whole state — counties, cities, and towns. Where the distances are too great, visits by laboratory personnel to the scene of the crime will be found inconvenient unless transportation by air is possible. The evidence in these cases is sent to the laboratory, which is usually located in the capitol or some other large city. It is possible for a number of smaller communities to pool their resources and talent in this matter and establish the equivalent of a laboratory of a large city.

To be specific in our treatment of this topic we shall discuss first the plan and equipment of a laboratory for a large city. It will be found that the equipment described here is rather more elaborate than that of the usual police laboratory. Later paragraphs will describe a smaller laboratory. The equipment, however,

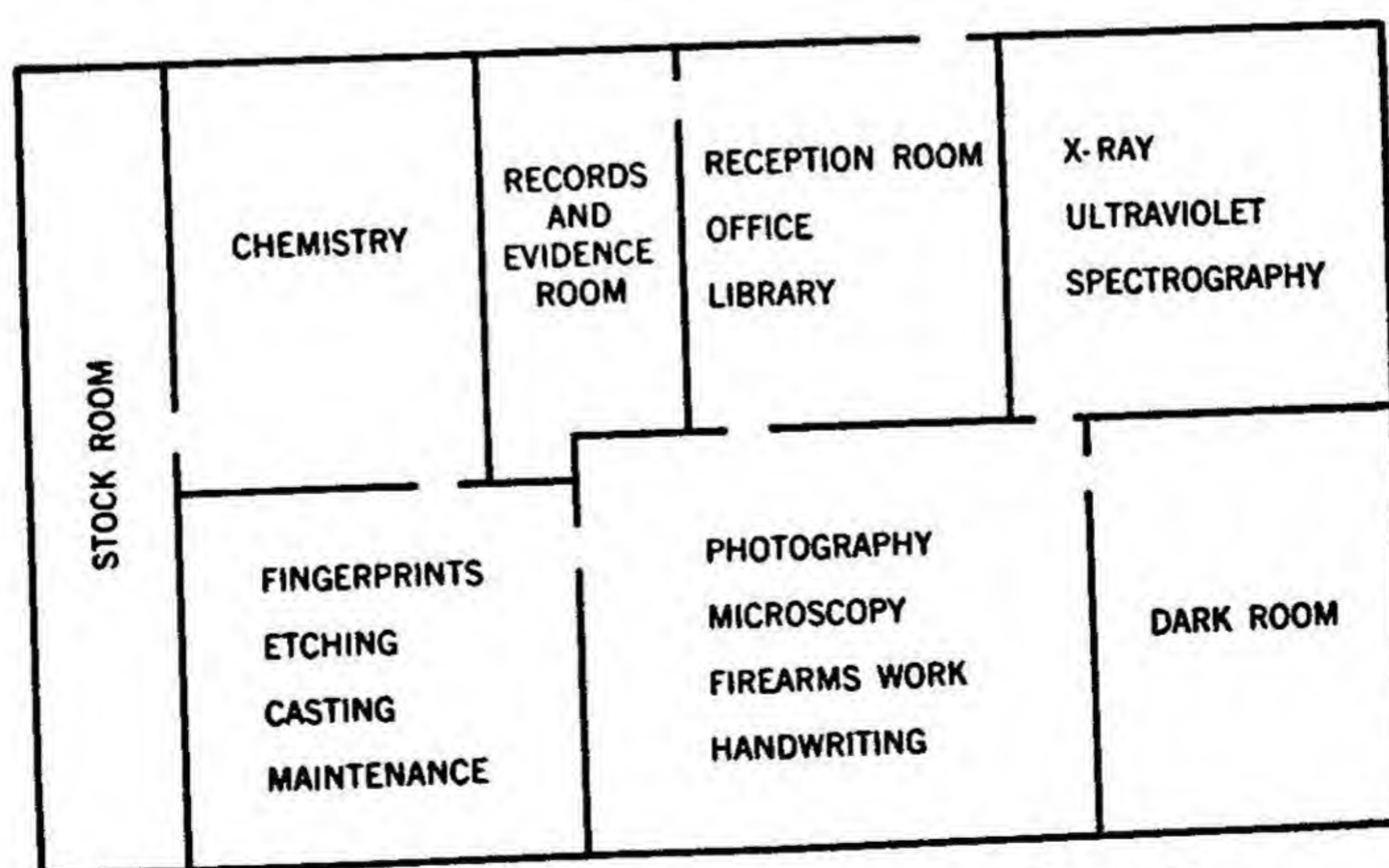


Fig. 1. Plan for a police laboratory in a large city.



is not the essential part of any laboratory. The minimum requirements of a police laboratory are fairly simple; the maximum requirements are unpredictable, since the ramifications of a scientific police investigation may reach out to any field of science and include its most modern techniques.

## 2. A LABORATORY FOR A LARGE CITY

The plan of a representative laboratory is shown in Fig. 1. The purpose of each room is given below together with the equipment it contains and a brief description of its use.

### Evidence and Record Room

In this room the evidence is stored during the time it is the subject of a laboratory investigation. A record is maintained of the date of delivery of the evidence to the laboratory, the persons permitted to examine it, and the date of delivery to the officer who first submitted it. The evidence room is lined with shelves on which are inscribed the numbers of the police divisions and precincts.

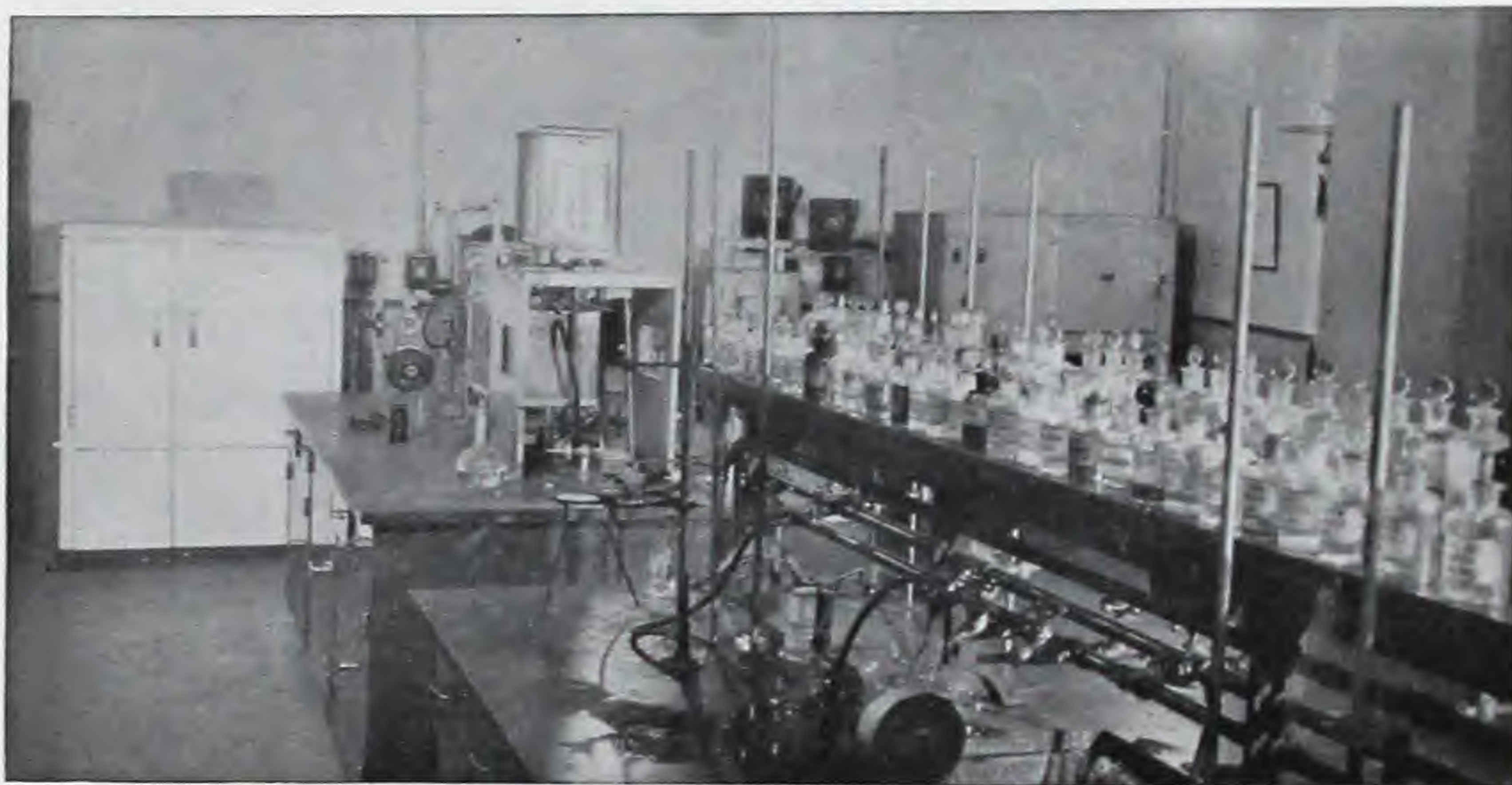


Fig. 2. Chemistry room, New York Laboratory.

Evidence is placed on the shelf bearing the number of the command from which the case originates. No unauthorized persons or visitors are permitted to enter this room. Laboratory records may also be kept in this room.

### Chemical Room

This room contains the usual services and equipment of a chemical laboratory such as laboratory tables, balances, hood, drying oven, gas analyzer, centrifuge, etc. For detection of the presence of small quantities of carbon monoxide a special indicating apparatus is used. This instrument is portable



and can be taken to the scene. A large refrigerator is used for storing blood samples, known sera, infra-red film, and perishable evidence.

### **Fingerprint and Physical Work Room**

A laboratory must have facilities for repairing the equipment and producing special apparatus and auxiliary equipment as the need arises. This room contains a complete set of tools and a bench lathe. The room is found suitable also for such work as fingerprint development, casting, polishing, and etching. The following such equipment is contained here:

Fingerprint work bench with soapstone top. Iodine fuming apparatus. White, black, aluminum, fluorescent, and other fingerprint powders.	— Latent fingerprints are developed here using powders, brushes, sprayers, iodine, and silver nitrate.
Palm print apparatus	— For taking palm or similar prints
Casting materials, double boilers, frames, brushes	— For plaster casts and moulage work
Work table with burners, small gas stove, water bath	— For casting and other work
Etching solutions, grinding and polishing apparatus	— For restoring deleted numbers on guns and other metal objects
Footprint apparatus	— For measuring foot line, step length, and angle
Vacuum cleaner, tube, and accessories	— For the extraction of dust in the examination of garments and similar objects
Electromagnetic retrieving arm, permanent alnico magnets	— For the recovery of metal objects weighing about 10 pounds, such as firearms thrown into sewers, lakes, or other inaccessible positions
Platform balance	— For weighing objects; preparing photographic solutions

### **Silver Nitrate Section**

Processing objects for the development of fingerprints is a frequently occurring task in the laboratory. The constant use of silver nitrate justifies a special sink over which processed objects can be hung to dry. A room which may be darkened is preferable, since processed objects are frequently left to hang overnight, and the presence of excessive light may overdevelop the prints without the operator's knowledge. Silver nitrate, mercuric chloride, running water, trays, rubber gloves, wooden clips, and wires suspended over the sink are sufficient equipment for this section of the room.



### Document Section

This equipment (Fig. 3) is used for the general examination of documents. Handwriting and typewriting comparisons, examinations of forgeries and erasures, investigations of age and character of paper or ink are conducted here. The following equipment is employed:

- Low-power binocular microscope — To examine overwriting, erasures, crossed lines, etc.
- Parallel beam lamp — This lamp is used to project a parallel beam of light across a paper in order to illuminate obliquely indented writing and documents bearing erasures.



Fig. 3. Document and Microscope rooms, New York Laboratory.

- Instruments, glasses, scales, and other devices — For the examination of questioned documents, graphometrical comparison of handwriting, measuring of thickness, size, and weight of paper, etc.
- Chemical reagents — Solutions for detecting and restoring erased writing
- Collection of inks — For reference purposes in comparisons and other work

### Microscopy and Firearms Identification Section

This room contains a number of standard optical instruments for physical examinations. The microscopes which are in the document section are also used



as needed. Illuminants, balances, and measuring devices are found in this room.

- |   |  |
|---|--|
| Chemical microscope                                   | — Capable of magnification up to about 400X  |
| Polarizing microscope                                 | — Another standard microscope equipped with polarizing prisms. This is used for petrographic examinations.   |
| Microscope measuring devices                          | — Micrometer eyepieces and stage scales for fine measurements with the microscope  |
| Comparison microscope                                 | — This is a microscope equipped with two objectives and one eyepiece permitting simultaneous examination of the evidence and test (or known) specimens.                              |
| Abbé refractometer                                    | — For determining refractive indices of liquids and solids   |
| Specific gravity balance and<br>Mohr-Westphal balance | — For quantitative work and for determining the specific gravity of liquids  |
| Thread counter  | — For making thread counts in comparison of specimens of cloth   |
| Standard sieves                                       | — A series of sieves of varying size for determining the average size and distribution of certain particles. Also for separating gravel and similar substances in earth examinations |
| Microtome   | — An instrument for making very fine sections of specimens such as hair, where it is desirable to cut without tearing or otherwise distorting the cross-sectional shape              |
| Microprojection apparatus                             | — For projection of the microscope field on a screen   |
| Microscope accessories                                | — Illuminants; vertical illuminator; dark field condensers, etc.   |
| Color comparator                                      | — For determining concentrations of colored solutions  |

### Photographic Section

- |                                 |   |
|---------------------------------|---|
| Commercial view camera, 8 by 10 | — For standard studio work — copying, enlarging, and reducing |
|---------------------------------|---|



- Contax or Leica type 35 mm — With 50 mm and 35 mm lenses camera
- Speed Graphic type 4 by 5 camera — This camera and the 35 mm type are convenient to use in investigations at the scene of a crime.
- Auxiliary Contax or Leica type camera equipment — Copying stand with attachments for low-power photomicrography; adapter for use of camera with microscope, etc.
- Photomicrographic camera — With a Micro-Tessar lens for low power and usual arrangement for high power
- Illuminants — Flood lamps for ordinary photographic work; special illuminants for photomicrography
- Stereoscopic camera and viewer — For three-dimensional photographs of small objects and also for low-power photomicrography in three dimensions
- Stereoscopic attachment for Contax or Leica type camera — For three-dimensional photographs of the scene of a crime
- Auxiliary lenses for 4 by 5 Speed Graphic — Telephoto and wide-angle lenses
- Light meter — For measuring illumination, and estimating exposure time,  $f/$  number, etc.
- Filters — For photography in visible, infrared, and ultraviolet spectral regions; polarizing screens for elimination of unwanted reflections
- Draftsman's drawing table and accessories — For sketches and drawings of the scene of a crime and articles of evidence

### Developing Section

- Developing and fixing tanks — Varying in size to hold negatives of different sizes
- Negative dryer — Air blower and heater for rapid drying
- Copying camera — A fixed-focus camera for making a one-to-one copy of a questioned document, fingerprints, or other paper where reproduction to exact size is required



**Printing Section**

Contact printer

— This should be large enough to handle up to 12-inch by 15-inch prints.

Enlargers

— These should be capable of enlarging 35 mm film and cut film, 8 by 10 being the largest size which, ordinarily, it is desired to enlarge.

Print dryer

— Gas-heated roller type for quick drying of prints

Mounting press

— For mounting photographs which are to be used as court exhibits

Stock solutions, trays, sink, etc.

— For processing prints

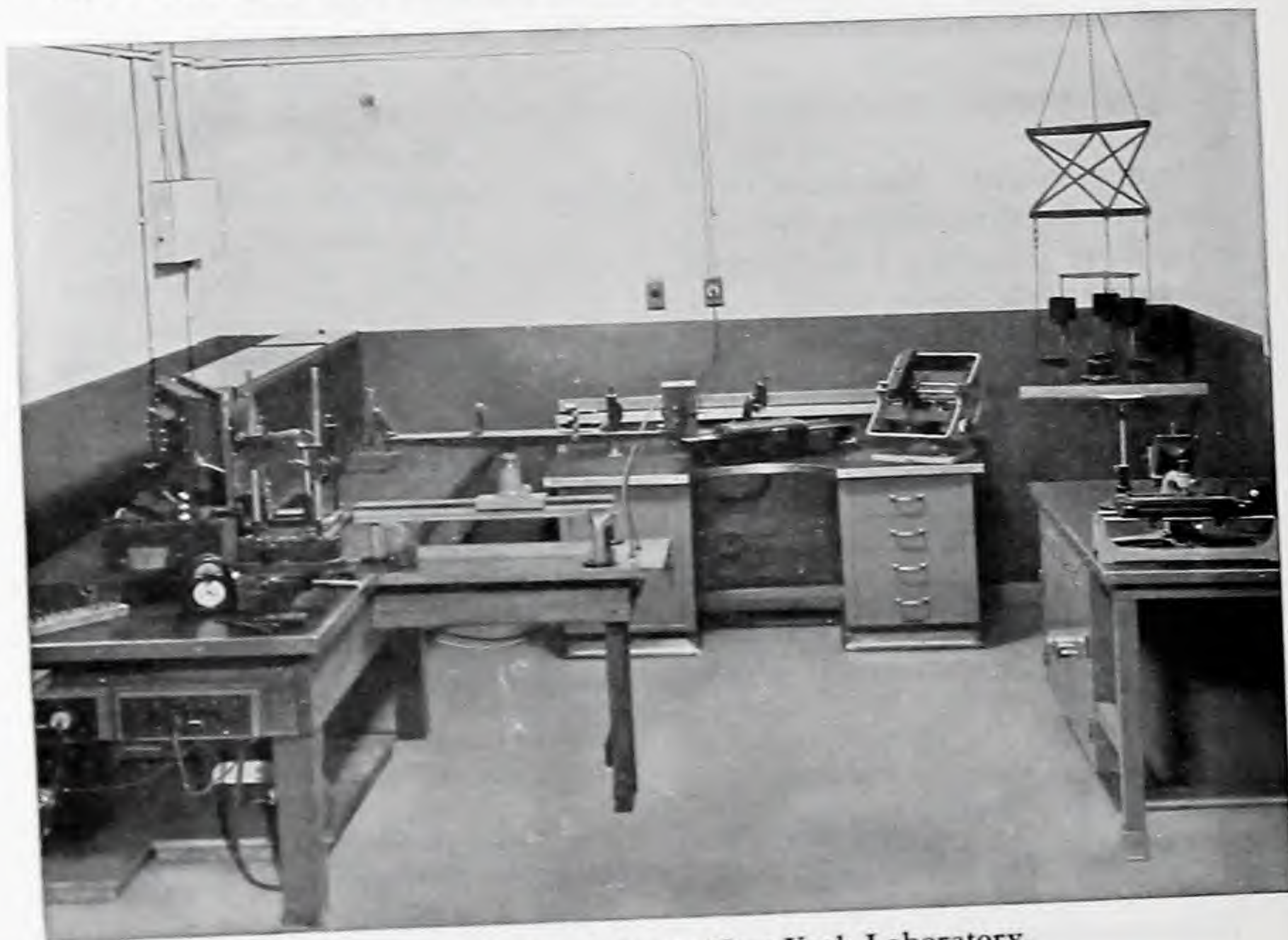


Fig. 4. Spectrograph room, New York Laboratory.

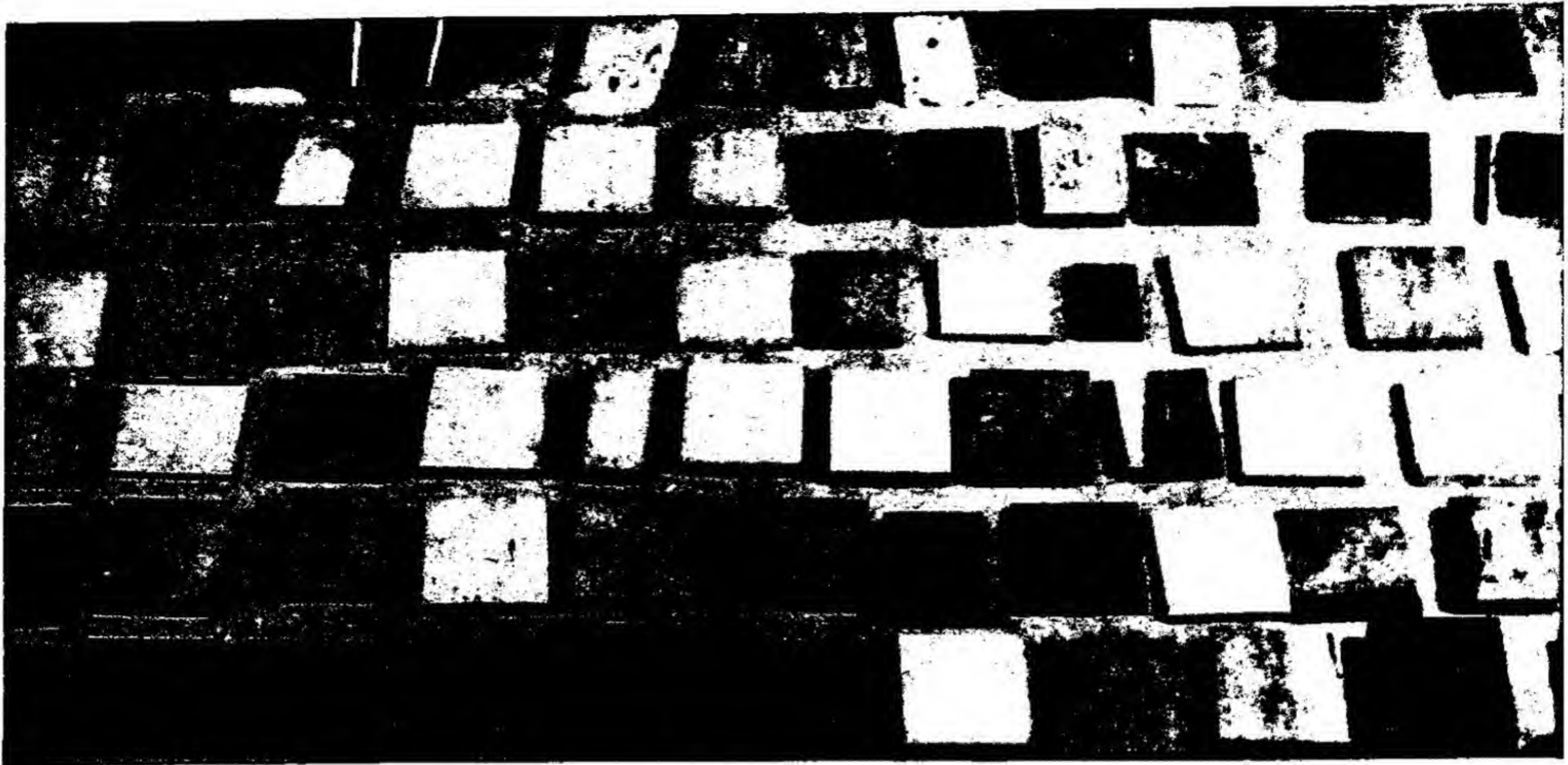
### Ultraviolet, X-ray, and Spectrograph Room (Fig. 4)

Another darkroom is needed for ultraviolet examinations. Since the x-ray unit is also contained in this room, the walls of the room are lead lined.

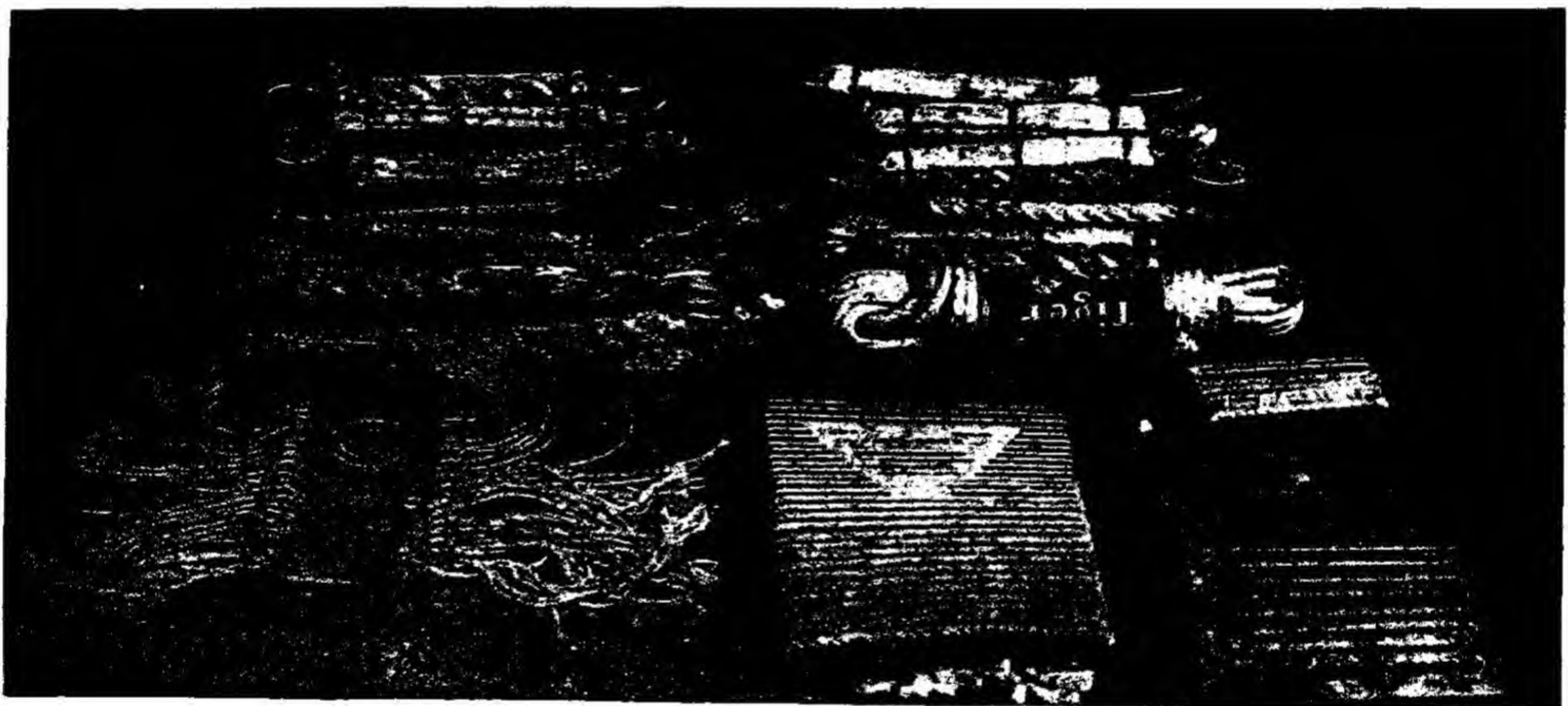
Ultraviolet lamp

— For ultraviolet examinations where fluorescence in the visible

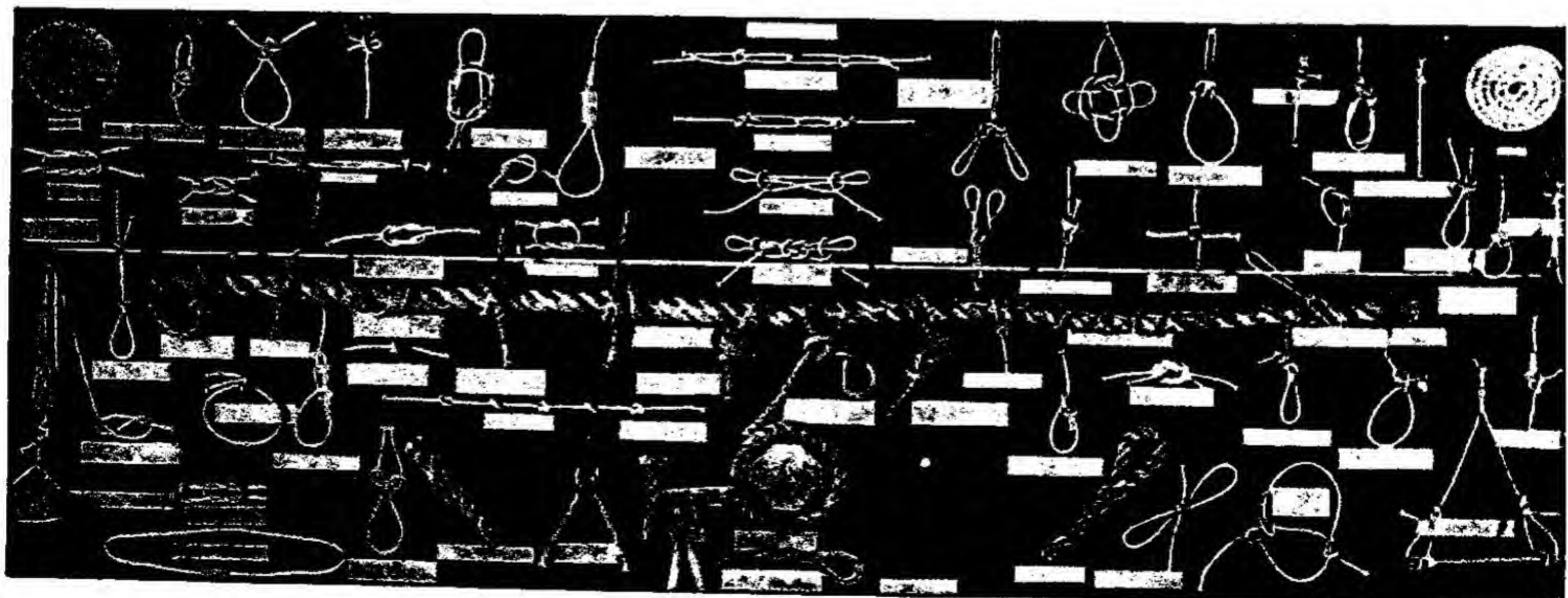




**Fig. 5. Reference collection of wood samples.**



**Fig. 6. Reference collection of cord samples.**



**Fig. 7. A collection of characteristic knots.**



X-ray units

Spectrograph, wave length micrometer, etc.

region is expected. This lamp is in daily use for document examinations, stains, etc. It should be equipped with filters for photography in the true ultraviolet region.

— For examining an object which, it is suspected, contains a hidden bomb. Loaded dice, defective mechanisms, and other material are also examined by means of x-rays.

— For the spectrochemical analysis of clue materials



Fig. 8. A case in which the identification of a knot offered a "lead."

### Stock Room

A reserve supply of expendable chemicals, apparatus and other material is kept in this room.

- |                                 |   |
|---------------------------------|---|
| Organic and inorganic chemicals | — An appropriate supply of necessary chemicals for standard procedures, research, etc   |
| Casting and molding material    | — For making casts of impressions by moulage, plaster, or plasticine  |
| Photographic materials          | — Pan, ortho, process, and infra-red film of various sizes; papers; lantern slides and positive film; flash bulbs and photofloods |
| Miscellaneous instruments       | — Measuring instruments, levels, protractors, cathetometer, spherometer, etc.   |



Auto lens collection	— For identifying broken headlight lenses
Auto tire collection	— Tire sections for identifying tire impressions
Wood, cord, and string collection (Figs. 5, 6, 7, 8)	— For comparison and identification of similar materials

### 3. A LABORATORY FOR SMALLER COMMUNITIES

The functions of a police laboratory can readily be fulfilled in a much smaller space and with considerably less equipment when the community served is relatively small or the crime rate is very low. Some cities limit the laboratory work to firearms identification, handwriting and other document examinations, fingerprint development, and routine photographic work. The nature of this work does not require employment of a person of extensive scientific training. Strictly speaking, however, such an establishment is not a police laboratory in the fullest sense. The forensic chemist is indispensable in criminalistics work. For this reason there will be included in the following plan all the essentials of the large laboratory without some of its conveniences and many of its less frequently used resources. Two rooms will suffice for the work.

#### Room 1

This room should be quite large since it is to be the general work room for chemical and physical analyses. The various sections of the room will be used as follows:

(a) *CHEMICAL LABORATORY SECTION*. This will occupy about one-third of the room and will be equipped with the necessary apparatus and chemicals. (No listing of these is necessary, since any competent chemist will be aware of the requirements in equipment.) In addition, the following equipment can be placed here:

1. A chemical microscope, with micrometer eyepiece, and illuminant
2. A small refrigerator for sera, blood samples, and perishable evidence
3. Small centrifuge
4. Chemical balance
5. Iodine fuming apparatus

(b) *PHYSICAL WORK SECTION*. A workbench and a vise should be in this section. Cabinets or drawers should be available containing the following equipment:

1. Set of tools
2. Measuring devices such as rulers, measuring tape, vernier and micrometer calipers
3. Fingerprint development equipment which will include assorted powders, dusters, lifting tape, and silver nitrate solution



4. Casting materials which will include plaster of Paris, modeling clay, positive and negative moulage material

(c) *DOCUMENT EXAMINATION SECTION*. A large desk should be set aside for this work. The following instruments should suffice:

1. Low-power binocular microscope
2. Hand magnifier
3. Protractors, scales, and other measuring devices

(d) *FIREARMS IDENTIFICATION SECTION*.

1. Comparison microscope

(e) *PHOTOGRAPHY SECTION*. The main feature of this section should be an 8 by 10 camera, such as a commercial view camera. In addition the following auxiliary equipment is needed:

1. A 35 mm type camera with 50 mm and 35 mm lenses
2. Auxiliary devices for low- and high-power photomicrography with the above 35 mm type camera
3. Filters, light meter, and floodlights

## Room 2

This is the darkroom. In addition to its photographic purpose it will serve also for ultraviolet examinations. The following equipment is needed:

1. A large sink, photographic trays, tanks, and stock solutions
2. A contact printer
3. An enlarger
4. Drying mechanism such as gas-heated roller or ferrotype tins
5. A small ultraviolet lamp

## GENERAL REFERENCES

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# **CHAPTER 3**

## **THE MOBILE LABORATORY UNIT**

### **1. NECESSITY FOR MOBILITY**

It has already been suggested that one of the most important functions of the criminalistician is the examination of the scene of the crime for physical evidence. After any serious crime such as murder, robbery, or burglary, the nature of which is such that traces of the criminals may reasonably be expected to be present, the scene should be guarded and the laboratory summoned. The detective without laboratory training is frequently unaware of many possible traces. He is often ignorant of the significance of seemingly unimportant details. In addition, his slight knowledge of the handling and preservation of evidence may lead to serious errors.

At the scene of the crime the laboratory investigator will often be required to make quick judgments. For example, his opinion will be requested concerning the possibility of certain stains being blood or semen. These tentative decisions are necessary to the work of the local detectives who are in charge of the case. Frequently they are confronted with circumstances which would permit suspicion to fall upon a number of persons. The eliminative aspect of the laboratory work in these circumstances is of great value. In addition to suggesting the possibilities that may arise from the first examination of the evidence, the laboratory man must decide what evidence should be removed to the office for further study and what method should be used for its preservation.

It is necessary, then, that a laboratory be equipped with facilities for making preliminary analyses and then collecting and preserving the evidence at the scene; hence it must possess a mobile unit. This unit need not be as pretentious as the term would seem to imply. The extent to which the unit is equipped will depend upon the budgetary resources and the size of the area in which the laboratory operates. For a small community a passenger car, camera, an intelligently planned kit will suffice. For a city the population of which exceeds 200,000, a truck with more elaborate equipment will be more suitable. State police require facilities for more extensive analyses at the scene, since in some cases they may be more than a hundred miles from their laboratory. We shall treat first the small community, then the large city, and finally a plan for extending



ing laboratory services to cover geographically large areas, such as a state or province, will be developed.

## 2. EQUIPMENT FOR THE SMALL UNIT

### (a) PHOTOGRAPHIC EQUIPMENT

1. Graflex or Speed Graphic type 4 by 5 camera with a bellows extension capable of one-to-one photographs; medium- and wide-angle lenses; tripod



Fig. 9. Set of tools for the mobile unit.

2. 35 mm type camera with accessories for magnifications, such as 1 : 1 size, for fingerprints
3. Fingerprint camera (the 35 mm will suffice for this purpose also)
4. Filters for various regions of the visible and infra-red spectrum; Pola-Screens
5. Film: pan, ortho, process, and infra-red
6. Photofloods; flash bulbs; flash gun
7. Flood lamps for outdoor examinations at night
8. Light meter
9. Ruler or scale



**(b) FINGERPRINT KIT**

1. Fingerprint camera (the 35 mm camera may also be used here)
2. Fingerprint powders: black, white, aluminum, and fluorescent
3. Brushes, sprayers, and iodine fumer for developing prints
4. Lifting tape
5. Roller, ink pad, and paper for taking prints of suspects

**(c) BLOOD-TESTING KIT**

1. Benzidine hydrochloride, glacial acetic acid, hydrogen peroxide normal saline solution, filter paper, blood stains dried on filter paper
2. Pillboxes, screw-top bottles, test tubes and stoppers for preserving samples of evidence
3. Dissecting kit containing scalpel, forceps, tweezers, scissors, needles probes, and spatulas
4. Medicine droppers, microscope slides, litmus paper
5. Labels, rubber bands, paper clips, pins
6. Rubber gloves

**(d) TOOL KIT (Fig. 9)**

Small and large wrenches, pliers, hammers, glass cutters, screw drivers and wire cutters

**(e) CASTING KIT**

1. Ten pounds of plaster of Paris
2. Sprayer, shellac, talcum, and cellulose acetate solution
3. Two large cups, one tablespoon, and a coarse sieve
4. Modeling clay

**(f) MISCELLANEOUS**

1. Thermometers covering range from -30 F to 350 F
2. Ruler, measuring tape, vernier and micrometer calipers
3. Hand magnifiers and dental mirrors
4. Flashlights, including a portable 6-volt storage battery floodlight
5. Boxes of assorted sizes for transporting evidence
6. Selection of organic solvents

**3. EQUIPMENT FOR THE LARGE UNIT**

A mobile unit designed for a large city should be contained in a medium sized truck (Fig. 10). In the front of the truck, directly behind the cab, a small darkroom may be located with a sliding lightproof door. In back of the dark room the truck may be lined on both sides with shelves for the necessary apparatus (Fig. 11). The contents of the darkroom and the rear compartment are listed in detail below.



**Darkroom**

- (a) Tank with three separate sections containing developer, water and hypo.  
A heater for the tank in cold weather should also be installed.
- (b) A small cabinet to contain the following:
  1. Interval timer
  2. Tank thermometer
  3. Photoflash and photoflood lamps
  4. Film holders, various sizes
  5. Film hangers, various sizes
  6. Thermometers to cover a range from  $-30^{\circ}\text{F}$  to  $350^{\circ}\text{F}$
  7. 14 by 17 x-ray film
  8. Film (4 by 5): pan, ortho, process, and infra-red



Fig. 10. Mobile unit of the New York Laboratory.

- 9.  $2\frac{1}{4}$  by  $3\frac{1}{4}$  film: pan, ortho, and process (for fingerprints)
- (c) X-ray rack:
  1. 14 by 17 film hangers
  2. X-ray high-speed cassettes
  3. 14 by 17 nonscreen holders

**Rear Compartments**

- (d) 1. Electromagnetic retrieving arm and alnico magnets — for retrieving metal objects from inaccessible places; they are most commonly used in retrieving guns from water, hence a long length of rope and wire is needed.
- 2. Storage battery for the above.



## THE MOBILE LABORATORY UNIT

2.

- (e) 1. Speed Graphic type camera (4 by 5), tripod, medium- and wide angle lenses.
- 2. Film holders, synchronizer, filters, Pola-Screen and other accessories Leica, Contax or Kodak 35 mm type camera.
- (f) 1. 110-volt floodlights
- 2. Portable 6-volt storage battery floodlight
- (g) Portable ultraviolet lamp — for examining stains, documents, etc.
- (h)\* Fingerprint kit
- (i)\* Blood-testing kit
- (j) 1. 85-kilovolt x-ray unit
- 2. 2 lead-lined aprons, 4 lead-lined gloves
- 3. Fluoroscope screen
- (k) 1.\*Plaster casting kit
- 2. Positive and negative moulage materials, modeling clay, foot casting form, face casting form, large pots
- 3. Electric hot plate
- (l) General supplies — fingerprint powders, specimen bottles, round pillboxes, oblong specimen boxes, tongue depressors, iodine fuming apparatus, rubber gloves, test tubes, test tube rack, dropper bottles, litmus paper, medicine droppers, filter paper, glass filters, assorted sizes of envelopes, gummed labels, selection of organic solvents, etc.
- (m) Complete set of tools
 

Hammer	Brace
Hatchet	Wood bits
Wood saws	Drill
Hacksaw and blades	Steel drills (Nos. 1-60)
Screw drivers — various sizes	Wrenches — assorted sizes and types
Pliers and cutters	Crowbar
Tin snips	Files
Wood chisels	Woodworking plane
Cold chisels	Pocket knife
Scraper	
- (n) 1. 110-volt, a-c generator — for supplying power to x-ray units, flood lamps, ultraviolet light, etc.
- 2. 100-foot extension line for generator
- (o) Greenough binocular microscope, hand magnifiers, and dental mirrors
- (p) Hand spectroscope
- (q) Compass
- (r) Voltmeter, ammeter, and ohmmeter
- (s) Folding ruler (6 ft), measuring tape (100 ft), vernier and micrometer calipers

\* As described for the smaller unit.



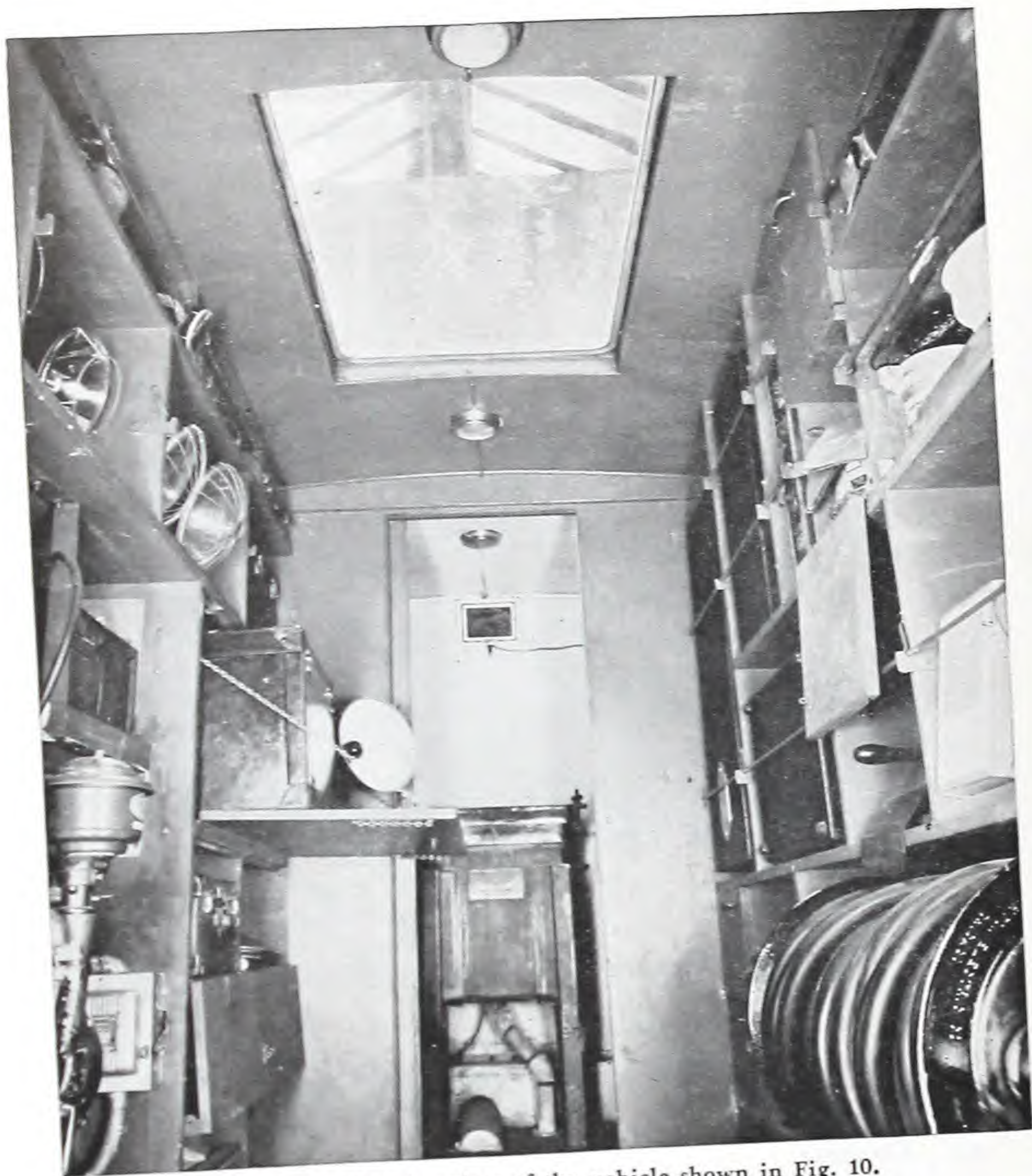
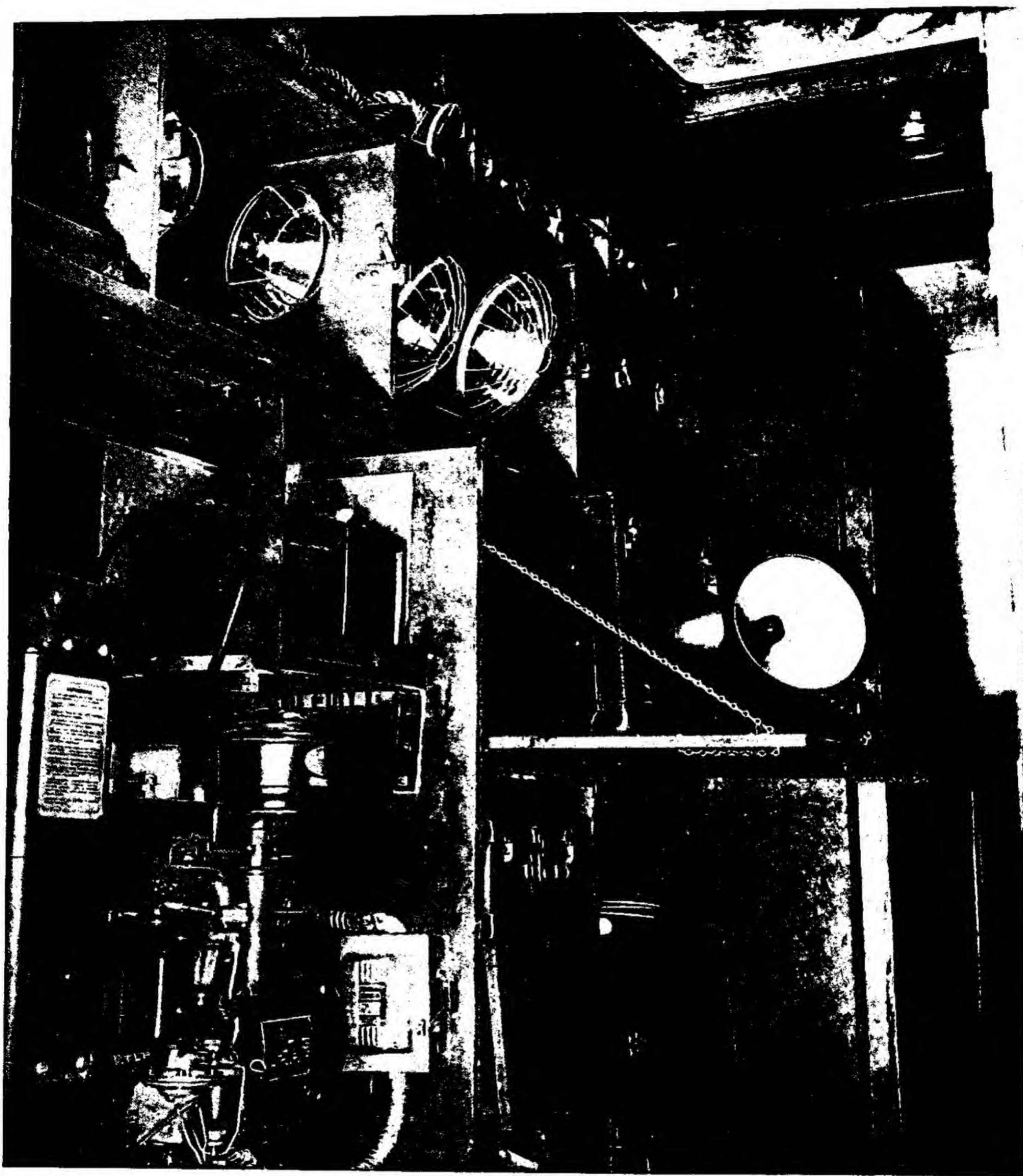


Fig. 11(a). Interior view of the vehicle shown in Fig. 10.





**Fig. 11(b). Left side of the interior of the vehicle shown in Fig. 10. (Designed by Act. Capt. Edward F. Fagan, Commanding Officer, Police Laboratory, New York Police Department.)**



#### 4. AIRBORNE UNIT FOR LARGE TERRITORIES

The field units thus far described have definite limitations in the extent of territory which they can effectively cover. A fifty-mile radius would seem to be the practical limit of coverage for these mobile field laboratories. Beyond this range the time consumed in traveling would prohibit effective use of the personnel and would permit perishable evidence to lose its value; moreover, the probability of detecting the criminal by means of physical clues decreases rapidly with passage of the first few precious hours when the trail is warm and the culprit is confused.

Confronted with this problem of distance, state laboratories have in the main relied upon the local police forces to forward the evidence by mail or to send it by messenger to the laboratory. This solution is by no means a happy one since the laboratories in such cases rely upon untrained personnel to evaluate physical evidence and determine the manner of collecting and preserving samples. It is far more satisfactory to have members of the laboratory go to the scene and do their own collecting, preserving, and evaluating.

The obvious method of meeting this problem is to transport the criminalist by airplane directly to the scene of the crime. Thus, within one or two hours of notification, the laboratory investigators can be at the scene of a crime, actively engaged in collecting evidence, and in some cases, making simple analyses. There is little question of the practicability of this plan with the present development of aviation. The presence of a large number of war-trained pilots in all countries removes any difficulty of obtaining personnel capable of piloting planes for this purpose.

The helicopter would perhaps be the most suitable plane for this work, since it eliminates the need for large landing fields. It offers, too, the advantage of permitting leisurely examination of terrain in searches and outdoor investigations. With a pair of good binoculars, long stretches of foot impressions or tire impressions can be readily followed.

The equipment for this airborne laboratory unit will be similar in most respects to that of the mobile laboratory unit for large cities. It should, however, be more elaborately equipped, since chemical analyses, blood tests, semen examinations, and other simple analyses should be done at the scene. The plane, then, will contain the equipment already listed for the large unit and in addition will contain equipment and chemical solutions for the following examinations:

- (a) Semen — Microscope and accessories such as illuminant, glass slides, cover glasses, and staining solutions
- (b) Blood — Precipitin tests:  
Known antihuman and antirabbit sera are required. (If the region to be covered is one in which hunting is popular, anti sera of animals that inhabit the region should also be carried. Experience will be helpful in determining these.)  
Grouping Tests:  
Known sera of Groups A and B, as well as blood cells of the same groups



- (c) Icebox unit — In order to preserve the known sera and blood cells as well as to prevent deterioration of any blood that it may be necessary to remove from the scene to the laboratory, some provision must be made for transportation of these materials at cool temperatures. A small metal insulated container with a special compartment for ice may be used for this purpose. The sera, blood cells, and evidence should be packed inside this container with cotton to absorb shock and mechanical strains. A vacuum jug may be filled with ice which may be used to replace the ice in the evidence container when necessary.
- (d) Carbon monoxide detectors

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## CHAPTER 4

# *THE CARE OF EVIDENCE; ITS PRESERVATION AND TRANSPORTATION*

The true value of evidence can be realized only if proper care has been used in observing the simple rules — scientific and legal — that should govern the journey of physical evidence from its discovery to its final appearance as a court exhibit. The steps in this procedure may be described as follows: (1) discovery of the evidence; (2) collecting the object or samples; (3) packing the evidence; (4) transportation to laboratory; (5) laboratory examination; (6) custody pending trial; (7) transportation to court; (8) exhibition in court. At present we shall be concerned with steps (2), (3) and (4) — collecting, packing, and transportation. Whenever practical, this work should be done by laboratory personnel, for several reasons: their experience can give a true evaluation of the evidence at the scene; since they are going to make the analysis, they are best qualified to judge what is needed; the chain of evidence has fewer links; much of the work of collecting samples is too technical for the average police officer.

### **1. GENERAL PRINCIPLES**

Frequently the task of collecting the evidence cannot be accomplished by a member of the laboratory; he must depend on intelligent assistance by other police officers because of the distance of the scene of the crime or because of the great difficulties that would be involved in the safeguarding of the evidence until his arrival. The following principles are given, then, for general guidance:

#### **Sufficiency of Sample**

It cannot be too strongly emphasized that the great error made in collecting evidence is that of insufficiency of sample. For some unaccountable reasons police officers are inclined to be niggardly in taking samples. This may in part arise out of an unqualified belief in the power of such analytical instruments as the spectrograph and the microscope. If an error must be made, let it be on the side of generosity.



**Inclusion of Standard or Known Sample**

If the evidence in question is found in the presence of a foreign substance, a sample of the foreign substance, also, should be taken; for example, if a blood-stain is found on linoleum, a sample of the unstained linoleum should also be submitted with the stained linoleum. In selecting the standard sample for future comparison purposes, care must be taken to include all materials from the scene which are likely to be found in the possession of or on the person of a suspect.

**Maintenance of Individuality**

Each bit of evidence must be collected and preserved as a separate sample. There must be no mixing or intermingling of unknown with known. For example, the glass found at the scene of a hit-and-run must not be placed in the same envelope as the glass taken from the automobile.

**Labeling**

To preserve the continuity and identity of the evidence, each sample should be labeled. Small fragments should be enclosed in specimen boxes; the boxes are then sealed with paper labels on which is written information concerning the nature and source of the sample, date and time of collecting, the case number, and the signature of the person who placed it in the box. Larger pieces can be enclosed in suitable envelopes which can be sealed. Tags should be available for pieces which are too large for envelopes. An identifying mark should be inscribed on large articles of evidence for later identification in court. An excellent device that may be used advantageously to mark evidence for identification is an electrically operated tool that vibrates at about 120 strokes per second. The tip of the needle of this tool permanently engraves identification marks on metals, wood, glass, plastics, and other hard objects. In the laboratory it is helpful in labeling microscopic slides, beakers, etc.

**2. COLLECTING AND PACKING**

The fundamental desiderata in collecting samples are sufficiency and purity of specimen and standard. In packing, the aim is to preserve the purity and original integrity of the samples. It will be assumed here that all instruments, bottles, slides, test tubes, envelopes, and pillboxes are clean. The slightest doubt in this matter should be dispelled by careful washing or by using another container.

The following specific procedures are recommended for the respective types of evidence:

**Articles Bearing Fingerprints**

**Weapons and Tools** — Knives, guns, tools, and similar weapons can be secured to a board by means of strings. Plyboard or wood with many perforations for the strings will serve the purpose. Pegs can be placed in some of the perforations to further secure the object. The board should then be placed in a special covered box in which it fits snugly.



Glass Pieces — Glass plates, thin marble and stone slabs, thin metal pieces, and other heavy objects of a similar shape can also be placed on a perforated board and secured by means of thin copper wire passing through the perforations and over the object. Another plyboard may be placed over the object and fastened by means of studding. Another scheme is to bend a number of small strips

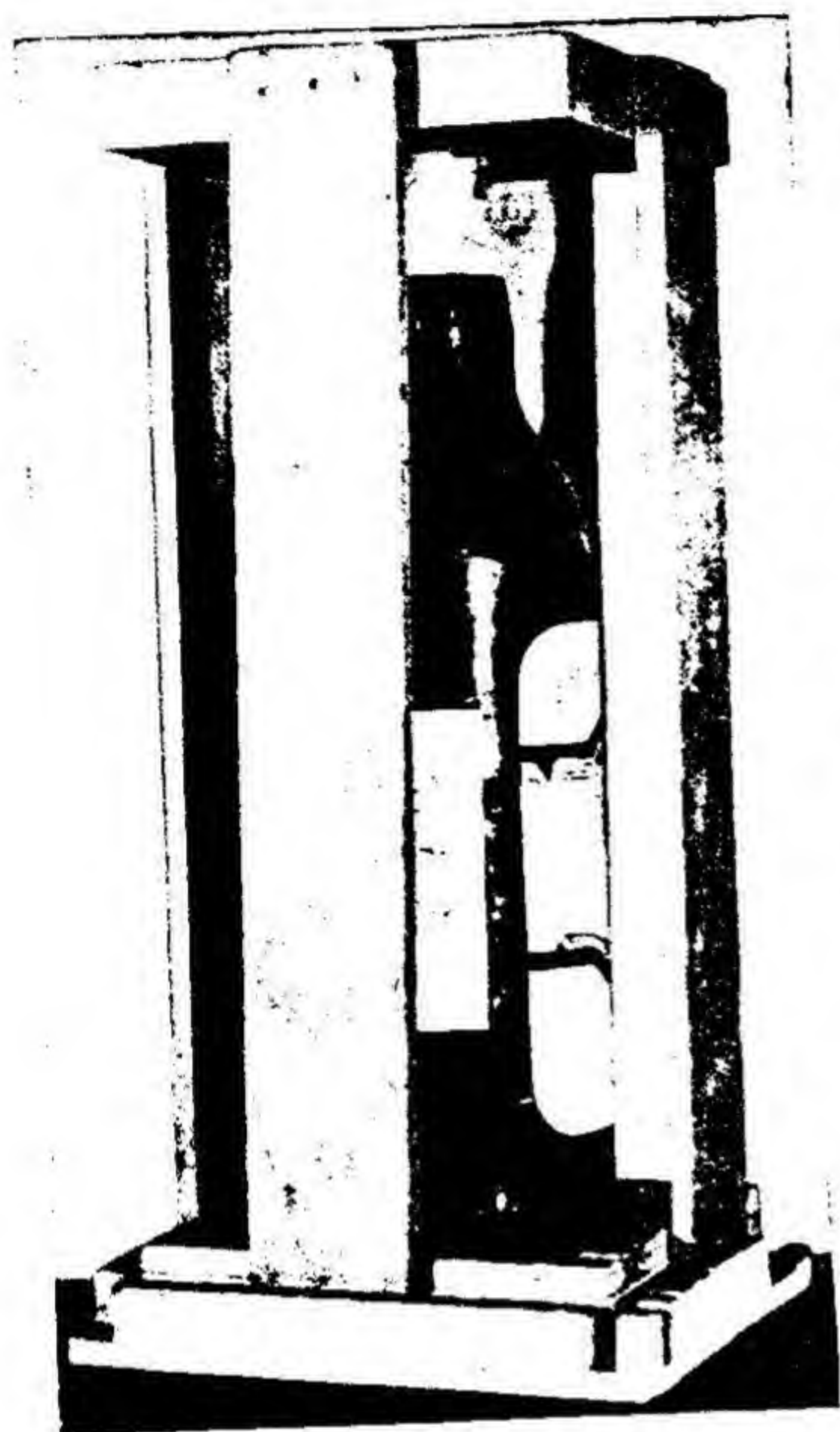


Fig. 12. Frame for the protection of prints on bottles.

of heavy cardboard over the edges of the object and then cover the object on both sides by means of two pieces of plyboard. Fasten the boards by means of studding.

Bottles, Glasses, Vases, etc. — These can be safeguarded by means of small wooden crates built for the individual object. Figure 12 is an example of such a construction. A simple crate can be built in the following manner: (a) trace out the periphery of the top and bottom of the object on two boards; (b) drive nails in a number of points on the trace; (c) fasten the top to the bottom with wooden strips.

Documents — These should be handled with wooden clips or tongs. No unnecessary folding should be made; where folding is necessary, the fold should be made along old lines. Manila envelopes may be used for transportation; it is preferable, however, to enclose a document in a glassine or other transparent envelope. Cleared photographic film may be used to construct suitable envelopes. The

advantage of the transparent holders lies in the facility provided for examining the document without handling it.

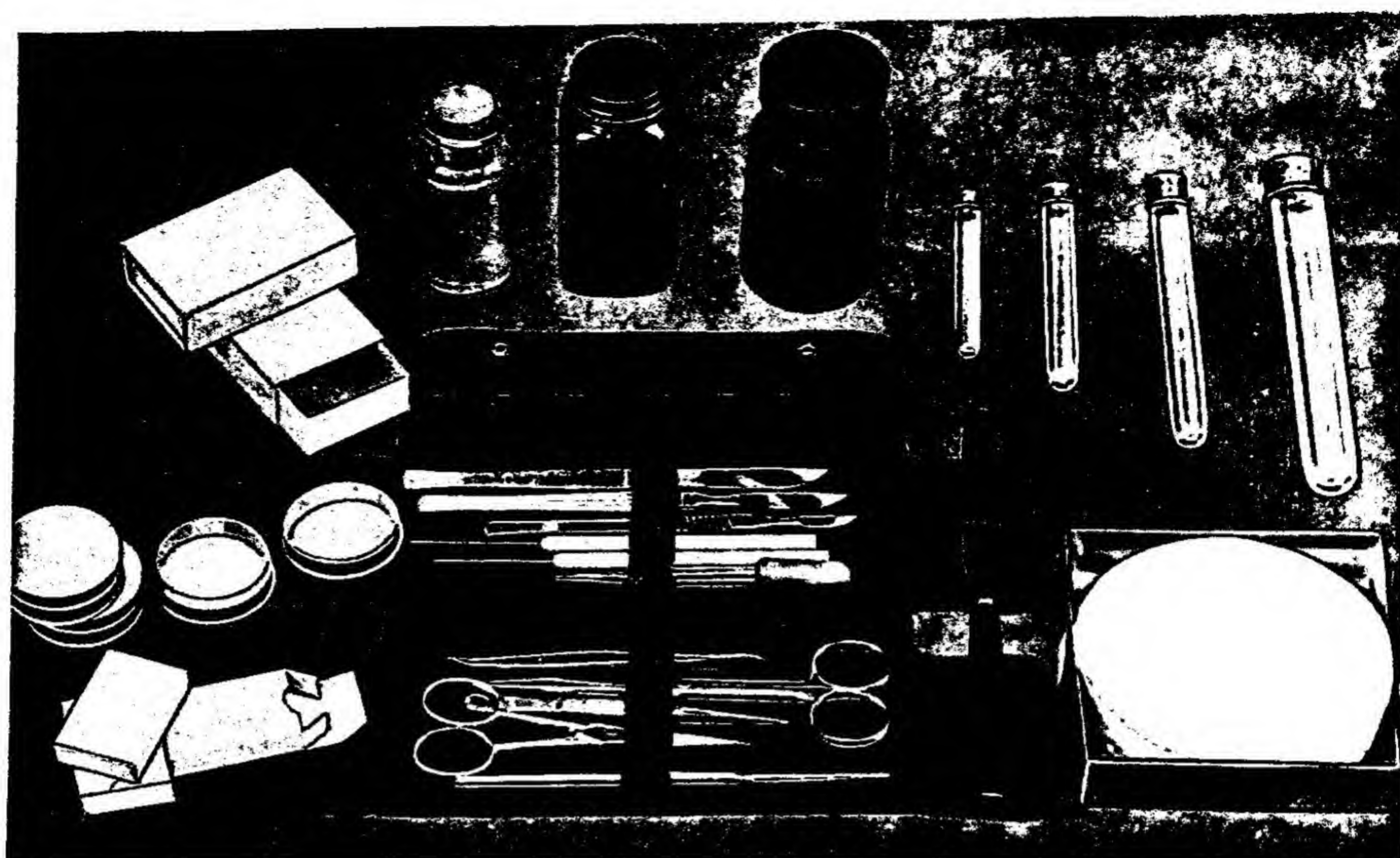
### Hairs and Fibers

If these are found adhering to some small object, (in a blood clot on a weapon, for example) the object itself should be brought to the laboratory with the hair or fiber remaining *in situ*. Forceps should always be used in picking up hairs or fibers in order to preserve untouched any foreign matter adhering to them. They should not be placed in an envelope or pillbox without further protection, since they may be lost on opening by a draft or a careless breath. The proper procedure is to place the hair or fiber in a filter paper, carefully fold the filter paper (without bending the hair) and enclose it in a pillbox.

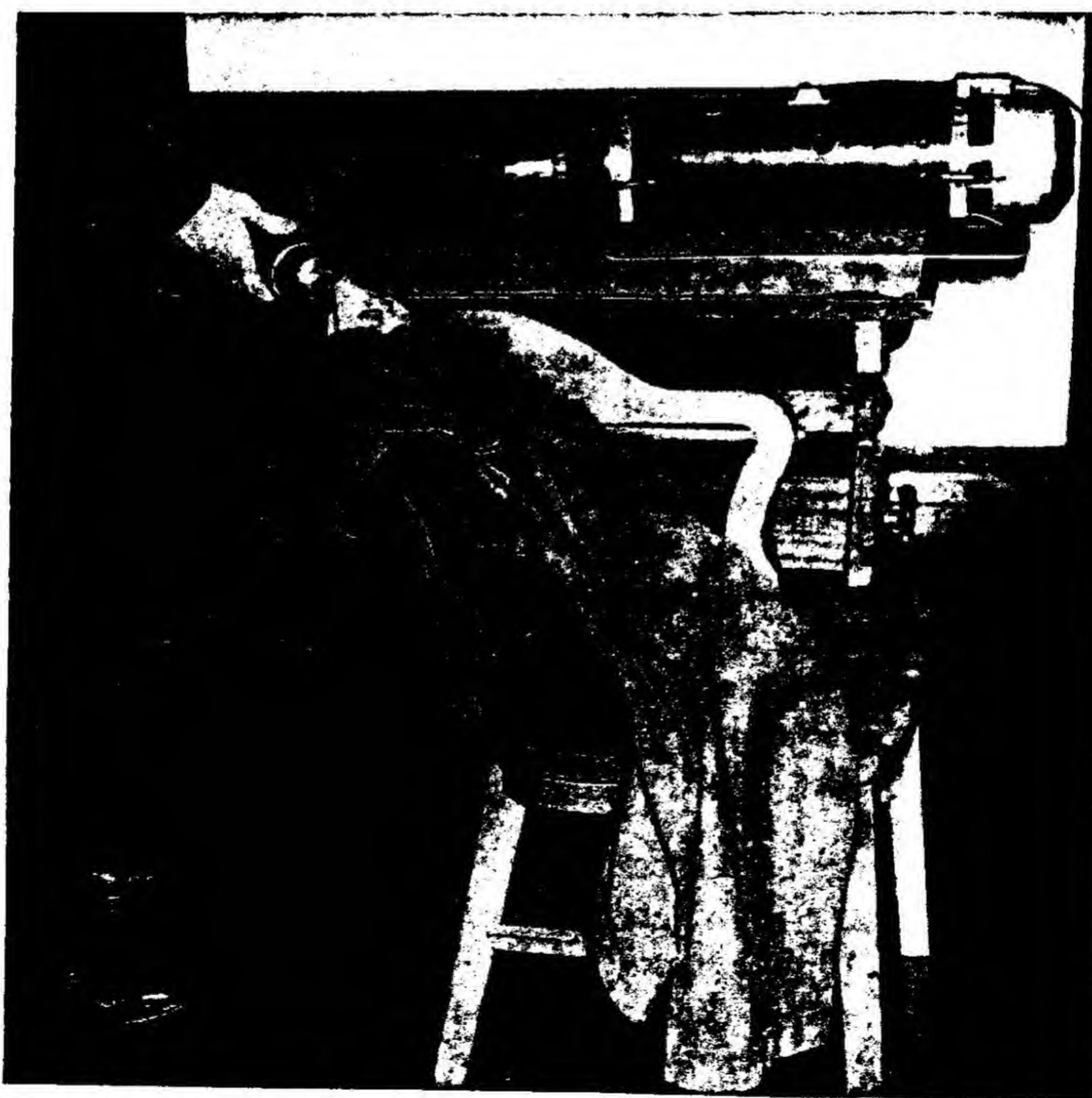
### Dust or Soil

If the matter in question is found on a shoe or other article of clothing or on an object which can be readily transported, it should remain *in situ* and the whole transported to the laboratory with proper protection. In other cases the dust or soil should be placed in a filter paper and then enclosed in a pillbox. The





**Fig. 13. Equipment for collecting samples at the scene.**



**Fig. 14. Collecting dust from clothing by means of a vacuum cleaner with a filter attachment.**



manner of collecting will depend upon the nature of the sample and the place where it is found. Dust on a sofa can be collected directly into a filter paper by means of a special vacuum cleaner device (Fig. 14). Soil may be collected by

means of a scalpel, spatula, or spoon. If the dust or soil is found on clothing, paper should be used to protect the separate folds of the clothing and the whole enclosed in a box.

### Other Particles

Metal filings, glass fragments, fingernail scrapings, paint chips, wood chips, plaster, and similar samples should be placed in filter paper and enclosed in a pillbox.

### Liquids and Greases

Glass containers with ground glass stoppers should be used.

### Semen

If the stain is still in a moist condition remove as much seminal fluid as possible by "milking" into a test

tube. Add distilled water sufficient to just cover the seminal fluid. A cork stopper is used to prevent the fluid from being spilled. The remainder of the stain is permitted to dry and treated in the same manner as a dried stain.

In the great majority of cases the alleged seminal fluid will have dried by the time it is ready to be transported to the laboratory. If the stained area is apparent (a laboratory investigator will find the portable ultraviolet light useful for this purpose) the garment or fabric may be folded, exercising care that the stained areas are not folded. Pieces of clean white paper should be interlaid between the folds. Unnecessary folding must be avoided. Under no conditions may the clothing be stuffed into a paper bag and conveyed to the laboratory in this manner, because experience has shown that spermatozoa are destroyed and lost by this careless method of handling.

### Blood

The following table is self-explanatory. It covers the usual conditions under which blood is found. If it is necessary to delay the transportation of blood to the laboratory for any length of time it is advisable to keep it at reduced temperatures (40 F–50 F) in an icebox or ice chest.



Fig. 15. Marking stained areas on a coat for further examination at the laboratory.



TABLE 1. Condition of Stain

Stains Found on	FRESH MOIST STAINS			DRIED STAINS	
	Small Quantities	Large Quantities		Small Quantities	Large Quantities
Clothing, sheets, blankets, rugs.	<p>Cut out <math>\frac{1}{2}</math> of stained area and place in test tube, just cover specimen with saline solution* and stopper.</p> <p>Allow remaining <math>\frac{1}{2}</math> of stain to dry at room temperature. Remove fabric to laboratory between clean, white paper inserted to protect stain from rest of material.</p>	<p>With a clean eye dropper transfer blood to a clean test tube, add <math>\frac{1}{2}</math> volume of saline solution* to test tube and stopper.</p> <p>Next procedure is to follow the directions given for small quantities.</p>		<p>Remove entire fabric to laboratory, interlaying white paper to protect stain.</p>	<p>Cut portion size of a square 5 cm on edge and place in a test tube, barely cover with saline* and stopper. Remove remainder of stain on fabric to laboratory in original condition, interlaying white paper to protect blood stain.</p>
Solid objects: (Stove, linoleum, cement, plaster, wood, automobile).	<p>Remove as much blood as possible with eye dropper, place in test tube, add <math>\frac{1}{2}</math> volume of saline,* stopper.</p> <p>Allow remainder of stain to dry, or if none can be removed with eye dropper, remove object to laboratory, if possible; otherwise scrape off stain with scalpel.</p>	<p>Remove as much blood as possible from object with an eye dropper, place in a clean test tube, add saline* (<math>\frac{1}{2}</math> volume) and stopper.</p> <p>Allow remainder of stain to dry and remove object to laboratory, if possible.</p>		<p>First remove any crusts. Place them intact in a test tube or pill box. Avoid breaking crust by rough handling.</p> <p>Remove object to laboratory. If impossible, scrape off as much as possible and place in clean test tube, stopper and remove to laboratory. Alternatively, saline* may be used to dissolve the stain — the solution being picked up with an eye dropper, placed in a clean test tube and stoppered.</p>	<p>First remove any crusts. Place them intact in a test tube or pill box. Avoid breaking crust by rough handling.</p> <p>Scrape off all blood possible. Divide into two portions. To one add saline* sufficient just to dissolve the blood; to other do nothing but stopper. Remove both tubes to laboratory. Remove object to laboratory, if possible.</p>

\* See p. 400.





Fig. 16. Collecting a blood sample at the scene of a burglary. In breaking through the window the burglar cut his hand.

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## PART B

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### PHYSICAL MEASUREME

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# CHAPTER 5

## TREATMENT OF DATA

A knowledge of the technique of measurements must form the basis of all sound laboratory work — industrial, research, or criminological. It is, however, frequently difficult to impress the beginner with the necessity of approaching even the simplest measurements in a scientific manner. When it is considered that the freedom of a defendant may depend upon the deductions made by a laboratory investigator from certain data, the science of measurement assumes a vital importance. For example, in a case of a motor vehicle homicide an expert may testify that the defendant's car was traveling at the illegal rate of 36.85 mph. This presumably four-figured accuracy may have no justification in the data. The correct conclusion may be that the car had been traveling at a speed between 30 and 40 mph. If the value of the speed attested to by the expert is close to the legal limit, say 35 mph, and forms the basis of the court's decision, it may happen that the defendant is unjustly found guilty. A correct treatment of the data and presentation of the conclusions would prevent such a miscarriage of justice through the misuse of science.

To avoid any misconception in a matter of such fundamental importance, an introductory treatment of the science of measurement is given here. A knowledge of measurement will be found to include a method of recording and treating data with an appreciation of the precision of instruments and a method of judging the reliability of results.

### 1. SIGNIFICANT FIGURES<sup>1</sup>

If in measuring with the meter stick, the smallest divisions of which are millimeter marks, it is found that the length of an object is 46.57 cm, it is evident that the end of the object lies between 46.5 and 46.6 cm, and that 0.07, although a reasonable estimate, is a doubtful figure. The number 46.57 is said to have four significant figures. A number such as 0.025 cm, where the 0.005 is doubtful, is said to have two significant figures, since the zeros *before* a digit serve only to fix the decimal point, which in turn depends on the size of the unit chosen. The number of significant figures used to record a measurement is, then, the number of certain figures of the measurement plus the first estimated or doubtful



figure; that is, the number of figures retained should be such that the uncertainty in the next to the last figure is not greater than unity.

According to this rule, in the operations of addition and subtraction, every digit is dropped which falls under an unknown digit in any of the quantities involved.

*EXAMPLE 1.*

$$\begin{array}{r} 8978 \\ 1.421 \\ 31.094 \\ \hline 9010.515 = 9011 \end{array}$$

(In discarding a digit over 5 add 1 to the next digit. In discarding 5 the digit which is now last should be even.)

In multiplication and division the number of significant figures retained in the result should not exceed the number of significant figures in the factor containing the least number of significant figures.

*EXAMPLE 2.* If the dimensions of a safe-deposit box are found to be 6.71 in., 8.53 in., and 5.10 in., what is the volume?

$$6.71 \times 8.53 \times 5.10 = 291.90513 = 292 \text{ cu in.}$$

A refinement of this rule sometimes justifies an additional significant figure. The refinement is the following:

In multiplication and division, the number of significant figures retained in each factor should be such that the percentage uncertainty in each factor will be no greater than that in the factor with fewest significant figures. For example, in the product  $23.82 \times 179.1 \times 0.078$ , the last factor contains only two significant figures. The uncertainty in this factor is at least one part in 78 or approximately one per cent. To preserve in the other factors an uncertainty of at most one per cent, three figures must be retained. Thus, the product becomes

$$23.8 \times 179 \times 0.078 = 332$$

A final rule concerning the number of significant figures to be retained in averaging: If four or more values are used in obtaining an average, an extra significant figure may be retained in the average. Averaging consists of two operations — summation and division. The application of the rules already given produces the results indicated by this special rule.

## 2. SCIENTIFIC NOTATION

For convenience, numbers such as 890,000 and 0.0000067 should be expressed as  $8.9 \times 10^5$  and  $6.7 \times 10^{-6}$ . The decimal point is usually placed after the first digit, and the proper power of ten is factored out. This notation is often used in scientific work where very large or very small numbers are involved.

## 3. AVERAGES OR CENTRAL TENDENCY

The repetition of a test or analysis leads to a series of measurements which can be best interpreted by an average. The *average* may be defined as a measure of the location of the central tendency. There are several kinds of averages,



which are suited to different purposes. Of these the arithmetic mean will be found to give the best representation of data in chemical and physical measurements. The simplest method of obtaining the arithmetic mean is to add all the individual measurements and divide by the total number of measurements.

$$\text{Thus} \quad \bar{X} = \frac{\Sigma X}{N} \quad (1)$$

where

$\bar{X}$  = arithmetic mean

$\Sigma$  = symbol indicating the sum

$X$  = individual measurement

$N$  = number of measurements

The arithmetic mean is the most commonly used and recognized average. The sum of the deviations (v.i.) about this point is zero and the sum of the squares of the deviations is less than that computed about any other point. The *deviation* of a single observation is defined as the difference between that observation and the average. Thus, the deviation  $x_1$  for an observation  $X_1$  is given by

$$x_1 = X_1 - \bar{X} \quad (2)$$

**EXAMPLE.** In the investigation of a hit-and-run accident it is found necessary to compare two samples of headlight glass by means of their physical properties. The following series of observations is obtained in measuring the refractive index of one of the samples: 1.32, 1.34, 1.35, 1.29, 1.34, 1.38, 1.33, 1.37, 1.36, 1.31. Compute the arithmetic mean and list the deviations.

$X$	$x$
1.32	-0.019
1.34	+0.001
1.35	+0.011
1.29	-0.049
1.34	+0.001
1.38	+0.041
1.33	-0.009
1.37	+0.031
1.36	+0.021
1.31	-0.029
$\Sigma X = 13.39$	
$\bar{X} = 1.339$	

It will be noted that the sum of the deviations about the mean is equal to zero:

#### 4. NORMAL DISTRIBUTIONS

In order to give meaning to the average value of a series of measurements, it is necessary to accompany it with a statement concerning the degree of variation which occurs about the average. The causes and nature of these variations will not concern us here. At present it is sufficient to say that deviations follow the *law of chance*. We may compare a series of measurements to a set of shots fired at a target. Let us assume that the target is a center vertical line flanked



by a series of lines, each one foot apart. The distribution of the shots in the spaces between the lines is found to be as follows:

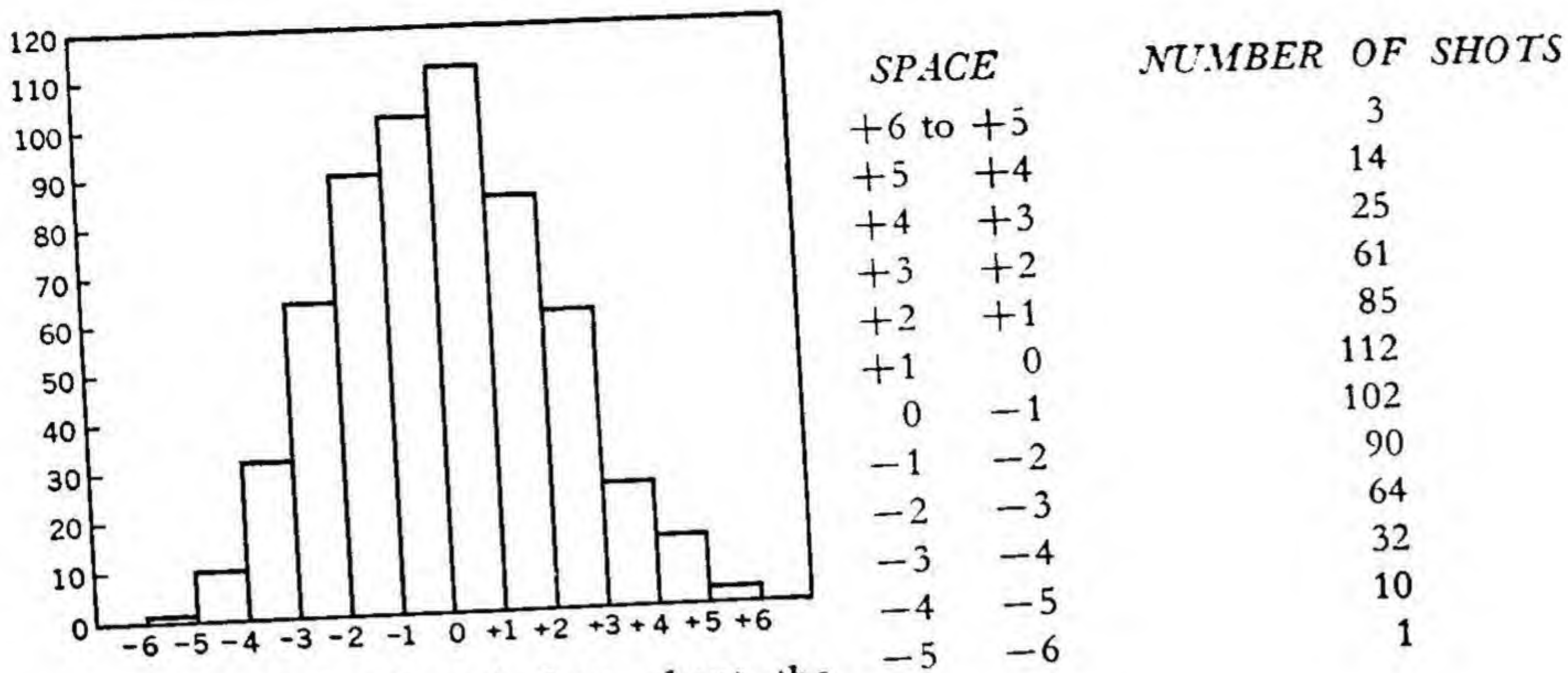


Fig. 17. Distribution of shots about the center vertical line.

If we plot the number of shots as ordinates and the spaces as abscissas, we obtain the graph in Fig. 17. The height of the rectangle constructed on each space represents the number of shots. If the number of spaces is indefinitely increased by narrowing the interval, a great number of shots will result in a graph such as Fig. 18. This curve is an example of a *normal probability curve*, and is typical for a chance distribution. In the statistical treatment of tabulated data of natural phenomena it is found that they are very frequently distributed ac-

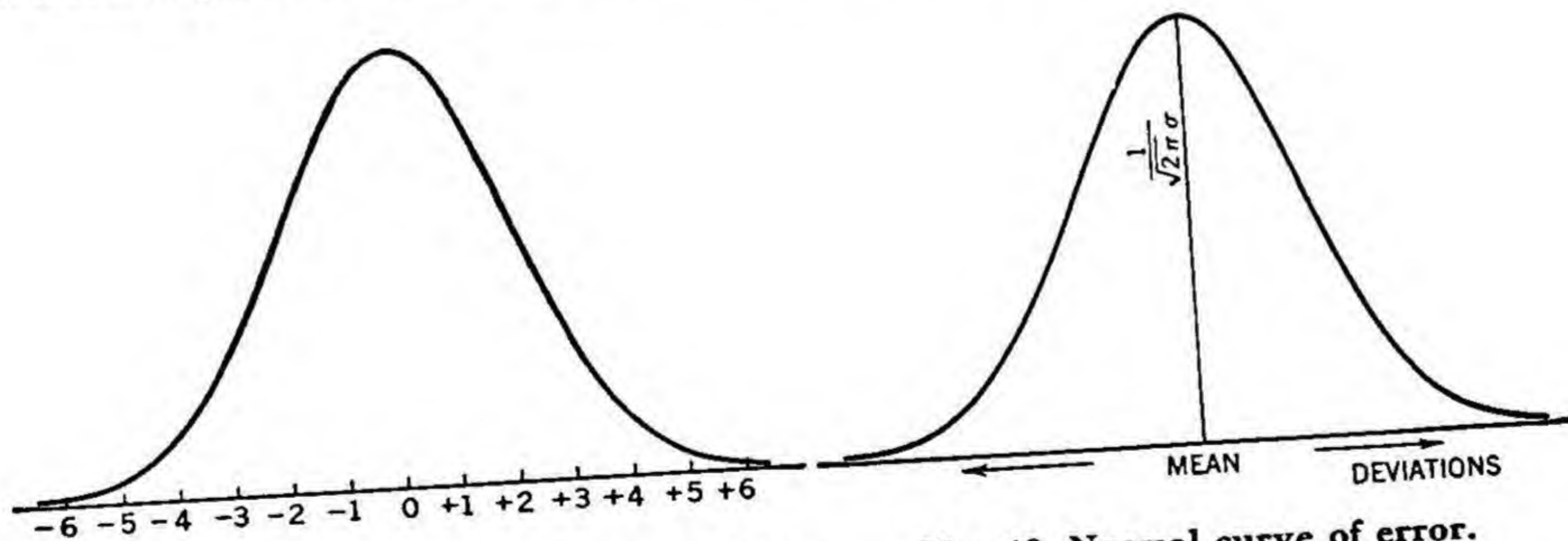


Fig. 18. Distribution of a very large number of shots.

Fig. 19. Normal curve of error.

cording to the *normal law*; i.e., their graph will be a normal probability curve. For example, the heights, chest measurements, or shoe sizes of a large number of people, randomly selected, will follow such a frequency distribution. If the results of an extensive series of measurements are plotted with ordinates representing the frequency of occurrence of a measurement, and the abscissas representing the deviations of the measurements from the mean, a curve such as



that of Fig. 19 is obtained. This curve is called the *normal curve of error*. The deviations or errors appear to be subject to a law of frequency distribution which is similar to that of a chance distribution. The curve possesses the following characteristics: (a) there are far more small errors than large ones; (b) positive and negative errors appear equally distributed.

## 5. DISPERSION

The dispersion of a set of measurements is an estimate of the extent to which the individual measurements are spread out from the mean. Thus, in Fig. 20 where the curves of two sets of measurements with the same mean are plotted, it is seen that in curve *a* the measurements cluster about the mean; whereas in curve *b* they are spread out a good deal more. The dispersion of curve *b* is greater than that of *a*. Hence we would say that the mean of curve *a* is more representative than that of *b*.

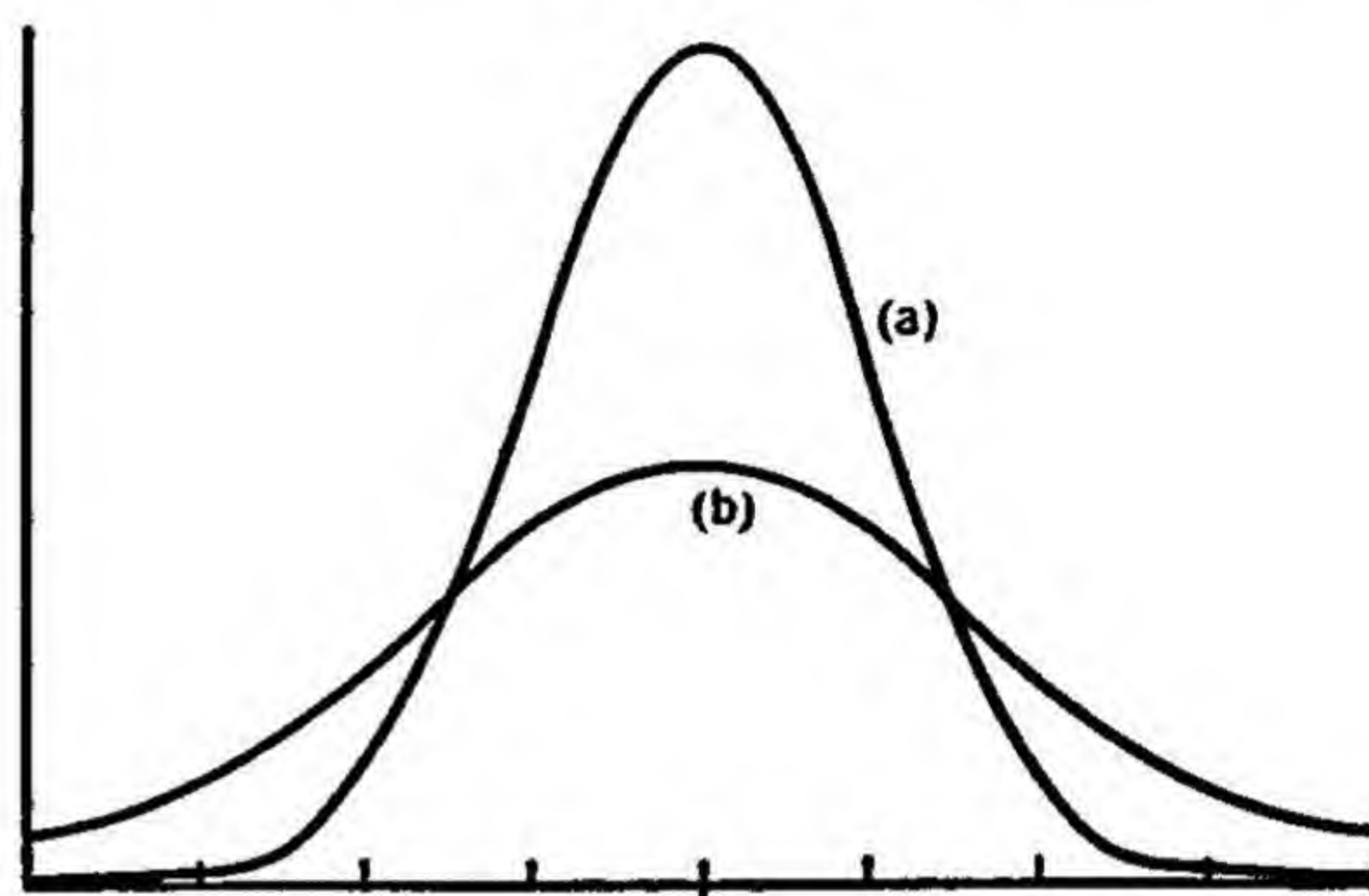


Fig. 20. Curves for two sets of data, indicating different dispersions.

Several quantitative measures of dispersion are in common use. For many purposes the *standard deviation*  $\sigma$  is satisfactory. This is defined as follows:

$$\sigma = \sqrt{\frac{\sum x^2}{N}} \quad (3)$$

where  $x$  is a deviation from the mean, and  $N$  is the total number of measurements. (Short cuts can be employed for the calculations of  $\bar{X}$  and  $\sigma$ .<sup>3, 4</sup>)

The standard deviation is affected by every measurement in the group and is sensitive to extreme values. It is a good measure of consistency, a large value of  $\sigma$  indicating considerable scatter about the average (as in curve *b*, Fig. 20). When very large values of  $\sigma$  are obtained, it is questionable that the average is a typical value.

**EXAMPLE.** Calculate the standard deviation for the data given in the preceding example.

Since

$$\begin{aligned} \sum x^2 = & (0.019)^2 + (0.001)^2 + (0.011)^2 + (0.049)^2 + (0.001)^2 + (0.041)^2 + (0.009)^2 \\ & + (0.031)^2 + (0.021)^2 + (0.029)^2 = 6.89 \times 10^{-3}, \end{aligned}$$

and

$$N = 10,$$

we have

$$\sigma = \sqrt{\frac{6.89 \times 10^{-3}}{10}} = 0.026.$$



Analytically the normal curve of error is represented by the equation:

$$y = \frac{e^{-\frac{x^2}{2\sigma^2}}}{\sqrt{2\pi}\sigma}, \quad (4)$$

where  $y$  is the frequency of occurrence of a deviation  $x$ , and  $\sigma$  is the standard deviation. (It is assumed for simplicity that the area under the curve is unity.)

It is seen that when  $x = 0$ ,  $y = \frac{1}{\sqrt{2\pi}\sigma}$ , which is the frequency for the mean.

If the value unity is given to the standard deviation, the equation becomes

$$z = \frac{e^{-\frac{x^2}{2}}}{\sqrt{2\pi}}, \quad (5)$$

the symbol  $z$  being used for the ordinate. The curve for this equation may be plotted with  $\sigma$  units as abscissas (Fig. 21). The area from the mean to any other  $x$  value will be denoted by  $\frac{1}{2}\alpha$ . The integral of  $z$  between two  $x$  values will give the value of  $\frac{1}{2}\alpha$ . Because of the importance of these three functions, a study of the following table of their values will be found useful:

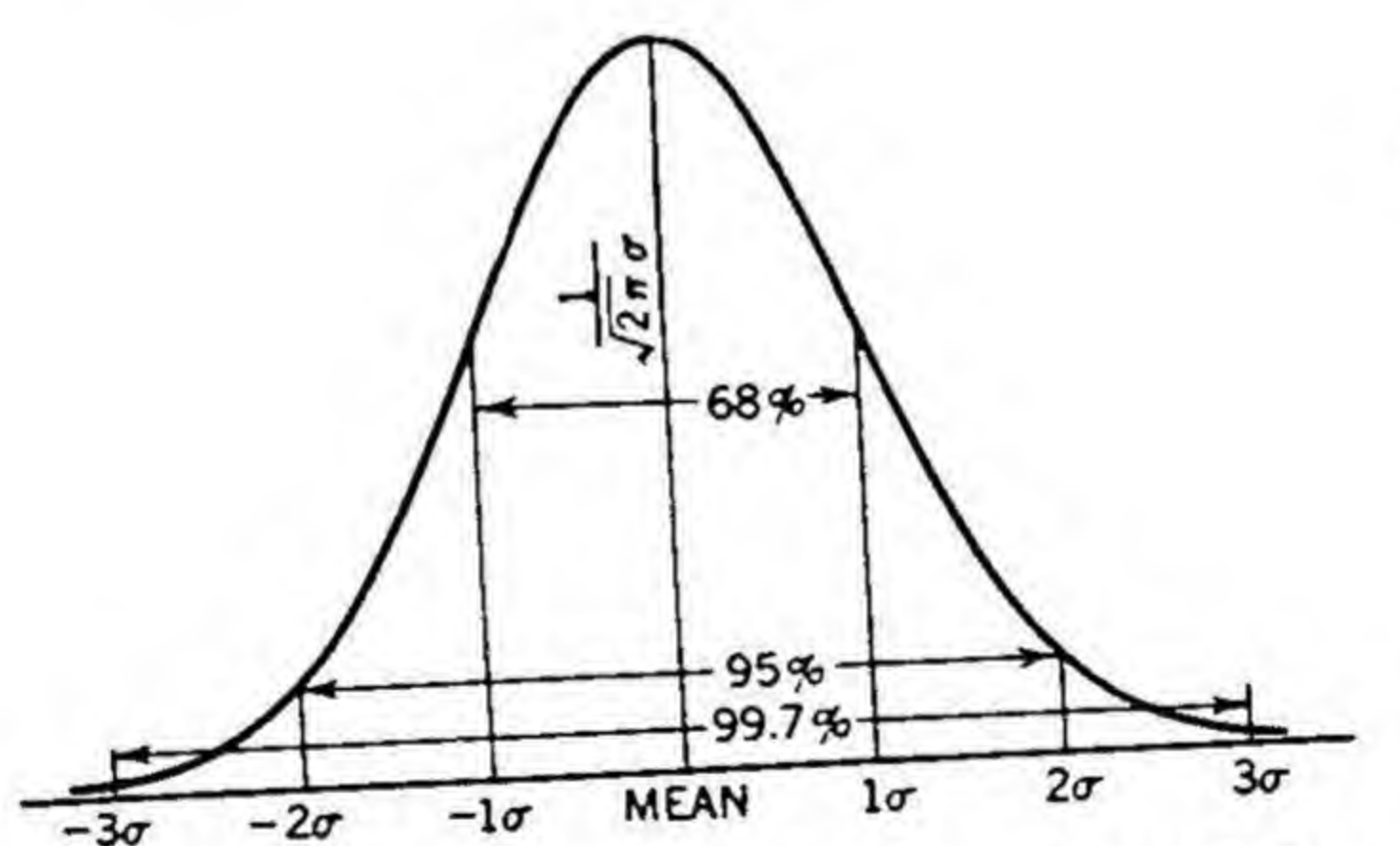


Fig. 21. Normal curve of error plotted in  $\sigma$  units.

TABLE 2

$x$ in $\sigma$ units	$\frac{1}{2}\alpha$	$z$
0.0	0.00	0.40
0.4	0.16	0.37
0.8	0.29	0.29
1.2	0.38	0.19
1.6	0.45	0.11
2.0	0.48	0.054
2.4	0.492	0.022
2.8	0.497	0.008
3.2	0.499	0.002
3.6	0.4998	0.001
4.0	0.5000	0.000

The area under the curve from  $-x$  to  $+x$  is  $\alpha$ . This area gives us the part of the frequency lying between the two limits. Thus between deviations  $x = -1$  and  $x = +1$  we find from the table that  $\alpha = 0.68$ ; i.e., 68 per cent of the deviations lie in a range of  $2\sigma$ . Between  $x = -2$  and  $x = +2$ , the area  $\alpha$  is 0.95; i.e., 95 per cent of the errors lie within a range of  $4\sigma$ . A range of  $6\sigma$  will include 99.7 per cent of the errors. Hence we can conclude that where there is a normal distribution, 95 per cent of the errors will lie within  $\pm 2\sigma$ , and 99.7 per cent will lie within  $\pm 3\sigma$ .

When  $\frac{1}{2}\alpha = 0.25$ , we find that  $x = 0.67$ . In other words 50 per cent of the errors are less than  $0.67\sigma$ . The value  $0.67\sigma$  is called the *probable error*,  $r$ . It is that



error for which the probability of its being exceeded is the same as the probability that it will not be exceeded. The definition of the probable error is given by

$$r = 0.67\sigma$$

or 
$$r = \pm 0.67 \sqrt{\frac{\sum x^2}{N}}. \quad (6)$$

**EXAMPLE.** Compute the probable error in the preceding example.

Since

$$\sigma = 0.026,$$

we have

$$r = \pm 0.67 \times 0.026 = \pm 0.017.$$

## 6. PRECISION INDICES

The *precision* or *reliability* of a series of measurements is the degree of consistency which they possess. In the example of the shots and the target, the precision would be considered good if all the shots were in one area. They might for example, be grouped about the  $-4$  line or the  $+2$  line. If, however, the shots were scattered about, the precision would be poor. The value of  $\sigma$  or  $r$  would show the degree of scatter, a large value indicating considerable scatter and poor precision.

The term *accuracy* or *validity* refers to the degree to which the measurements approach the "true" value. In the target example a set of shots closely grouped about the center line would indicate great accuracy (as well as great precision). A set of shots grouped about line  $+3$  would indicate good precision but poor accuracy. An automobile speedometer which *fluctuates* about a mean value of 25 when the car is traveling at 25 mph may be said to have poor precision but good accuracy. If the indicator *remains steadily* at 30 when the car is traveling at 25 mph, the instrument has good precision but poor accuracy. Since the "true" value of the quantity which is being measured is seldom known, we usually have no way of measuring accuracy.

The two most common measures of precision are the indices  $\sigma$  and  $r$ . Although there is no particular advantage in using the probable error in place of the standard deviation, it is in common use among physicists and chemists and will therefore be employed here as a precision index.

It is shown in the theory of errors that the mean of a set of  $N$  measurements is  $\sqrt{N}$  times more reliable than any of the individual measurements. The standard deviation for the mean is called the *standard error of the mean* ( $\bar{\sigma}$ ). The formula for this quantity is

$$\bar{\sigma} = \frac{\sigma}{\sqrt{N}}. \quad (7)$$

Similarly the *probable error of the mean*,  $\bar{r}$ , is given by

$$\bar{r} = 0.67 \frac{\sigma}{\sqrt{N}}. \quad (8)$$

**EXAMPLE.** Compute the standard error and the probable error of the mean in the example of the preceding section. (For simplicity assume  $N = 9$ .)

$$\bar{\sigma} = \frac{\sigma}{\sqrt{N}} = \frac{0.026}{3} = 0.0087,$$



and

$$= 0.67 \frac{\sigma}{\sqrt{N}} = 0.67 \times 0.0087 = 0.0058.$$

## 7. STATISTICALLY RELIABLE DIFFERENCE

In the work of criminalistics a small difference between two means can be of great significance. In measuring, for example, the density of two specimens of glass, a mean value together with a probable error will be obtained for each. The means may differ by small amounts. A criterion must be employed to determine whether this difference is due to chance or represents a significant difference.

From the normal curve it is seen that there are 997 chances out of 1000 that any error occurring will not be greater than 3 standard deviations ( $3\sigma$ ). If we use the probable error as a dispersion measure, we can say that there are 993 chances out of 1000 that the error will not be greater than four probable errors ( $4r$ ). An error greater than  $4r$  is often referred to as a *statistically reliable difference*.

In calculating the results of two experiments the values  $\bar{X}_1 \pm \bar{r}_1$  and  $\bar{X}_2 \pm \bar{r}_2$  will represent the means of the two sets of measurements. The difference between the two means is

$$\Delta = \bar{X}_1 - \bar{X}_2$$

The probable error of the difference is (v.i.)

$$R = \sqrt{\bar{r}_1^2 + \bar{r}_2^2} \quad (9)$$

If  $\Delta$  is greater than  $4R$ , it may be concluded that the probability that this difference is attributable to chance is less than 7 over 1000.

**EXAMPLE 1.** A pair of suspected dice is submitted to the laboratory for examination. On measuring one die (Fig. 22) it is found that the dimensions of the sides are not uniform. (The

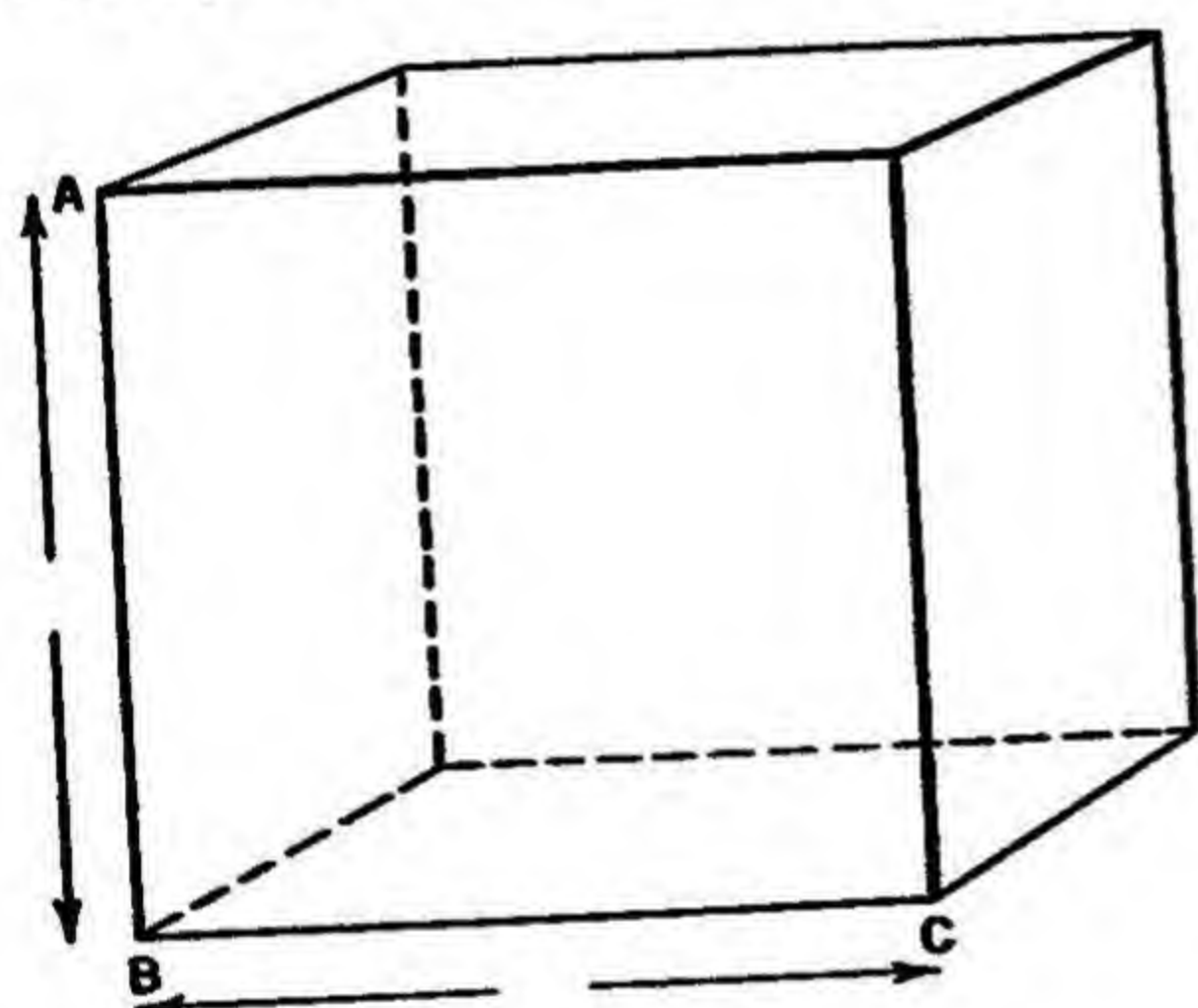


Fig. 22.

dice are "bricks" or "flats"). The following series of measurements are obtained for the lengths  $AB$  and  $BC$  (in mm).

Length $AB$			Length $BC$		
$X$	$x$	$x^2$	$X$	$x$	$x^2$
30.3	-0.1	0.01	29.9	+0.04	0.0016
30.7	+0.3	0.09	29.6	-0.26	0.0676
30.4	0.0	0.00	30.1	+0.24	0.0576
30.6	+0.2	0.04	29.8	-0.06	0.0036
30.3	-0.1	0.01	30.0	+0.14	0.0196
30.4	0.0	0.00	29.8	-0.06	0.0036
30.1	-0.3	0.09	29.7	-0.16	0.0256
30.5	+0.1	0.01	30.0	+0.14	0.0196
30.3	-0.1	0.01	29.8	-0.06	0.0036

For length  $AB$  we have the mean

$$\bar{AB} = \frac{\sum X}{N} = \frac{273.6}{9} = 30.40$$



The probable error in  $\overline{AB}$  is given by

$$\bar{r}_{\overline{AB}} = 0.67 \frac{\sqrt{\sum x^2}}{N} = \frac{0.67 \sqrt{26 \times 10^{-2}}}{9} = 0.037$$

and  $\overline{AB} = 30.40 \pm 0.037$ .

Similarly for length  $BC$ ,

$$\overline{BC} = \frac{268.7}{9} = 29.86$$

and  $\bar{r}_{\overline{BC}} = 0.033$

Hence  $\overline{BC} = 29.86 \pm 0.033$ .

The difference between the two means is

$$\Delta = \overline{AB} - \overline{BC} = 30.40 - 29.86 = 0.54;$$

and the probable error of the difference is given by

$$R = \sqrt{\bar{r}_{\overline{AB}}^2 + \bar{r}_{\overline{BC}}^2} = \sqrt{(0.037)^2 + (0.033)^2} = 0.05$$

Since  $4R = 0.20$ ,  $\Delta$  exceeds  $4R$  and we have a statistically reliable difference. (The question of whether this difference affects the "roll" of the dice is a separate consideration.)

**EXAMPLE 2.** Two samples of cord are submitted to the laboratory in a homicide investigation. It is required to compare the strength of Sample 1 with that of Sample 2. The following readings for strength  $m$  are obtained for the two samples. Calculate the standard deviation, standard error, and probable error for each sample. Determine whether a real difference exists.

SAMPLE 1		
$m$	$x$	$x^2$
57.0	+2.39	5.71
54.4	-0.21	0.04
51.3	-3.31	10.96
56.2	+1.59	2.53
53.6	-1.01	1.02
52.1	-2.51	6.30
57.4	+2.79	7.78
53.8	-0.81	0.66
55.7	+1.09	1.19
9)491.5		9)36.19
54.61		4.02

$$\bar{m}_1 = 54.61$$

$$x_1 = \sqrt{4.02} = 2.0$$

$$\bar{\sigma}_1 = \frac{2.0}{\sqrt{9}} = 0.67$$

$$\bar{r}_1 = 0.67 \times 0.67 = 0.45$$

$$\bar{m}_1 = 54.61 \pm 0.45$$

SAMPLE 2		
$m$	$x$	$x^2$
50.1	-0.56	0.31
51.2	+0.54	0.29
53.6	+2.94	8.64
47.8	-2.86	8.18
49.2	-1.46	2.13
50.7	+0.04	0.00
52.6	+1.94	3.76
48.3	-2.36	5.57
52.4	+1.74	3.03
9)455.9		9)31.91
50.66		3.55

$$\bar{m}_2 = 50.66$$

$$\sigma_2 = \sqrt{3.55} = 1.9$$

$$\bar{\sigma}_2 = \frac{1.9}{\sqrt{9}} = 0.63$$

$$\bar{r}_2 = 0.63 \times 0.67 = 0.42$$

$$\bar{m}_2 = 50.66 \pm 0.42$$

$$\Delta = 54.61 - 50.66 = 3.95$$

$$R = \sqrt{\bar{r}_1^2 + \bar{r}_2^2} = \sqrt{(0.45)^2 + (0.42)^2} = 0.62$$

$$4R = 2.48$$

Since  $3.95 > 2.48$ ,  $\Delta$  exceeds  $4R$  and we may say that a statistically reliable difference exists between the strengths of the two samples.



## 8. REJECTION OF INDIVIDUAL READINGS

We can determine from Table 2, the fractional part of the errors which may be expected to lie outside of a given range. This table gives us  $\alpha$ , the area or fractional part of the readings corresponding to  $x/\sigma$  values. Thus if  $\sigma = 0.08$  and  $x = 0.19$ , we have  $x/\sigma = 2.4$  and, from the table,  $\alpha = 0.98$ . It can be said, then, that 98 per cent of the deviations may be expected to lie between 0 and  $\pm 0.19$ . We can conclude also that  $1 - 0.98$  or 0.02 (i.e., 2 per cent) of the errors will be greater than 0.19.

Table 2 enables us to employ a criterion for the rejection of individual readings which appear to differ greatly from the other members of a series. This criterion is due to Chauvenet. A reading is rejected if its deviation,  $x$ , is such that errors greater than (or equal to)  $x$  represent an  $\alpha$  which does not exceed  $\frac{1}{2N}$ , where  $N$  is the total number of readings in the series. Thus if  $1 - \alpha$  does not exceed  $\frac{1}{2N}$  for a given  $x$  and  $\sigma$ , we reject the reading corresponding to  $x$ .

For example, in a series of 10 readings

$$1 - \alpha = \frac{1}{2N} = \frac{1}{20}; \quad \text{or} \quad \alpha = 0.95$$

From Table 2 we see that corresponding to  $\alpha = 0.95$ , we have the value 1.96 for  $x/\sigma$ , and hence

$$x = 1.96\sigma$$

We thus reject a reading if its deviation is greater than  $1.96\sigma$ . In terms of probable error, we reject a reading if the deviation is greater than  $2.93r$  (substituting  $r = 0.67\sigma$ ).

This procedure may be repeated for various values of  $N$ . In this manner Table 3 can be formed:

TABLE 3

$N$	$\frac{x}{r}$
5	2.5
10	2.9
15	3.2
20	3.3
50	3.8
100	4.2

where  $N$  is the number of observations made in the experiment. The probable error  $r$  is calculated, and the deviation  $x$  from the mean is determined for the suspected observation. If the ratio  $x/r$  exceeds the ratio given in the table opposite the appropriate value of  $N$ , the suspected observation should be rejected.

**EXAMPLE 1.** In the course of a typewriting comparison it is found necessary to determine the height of the letter "b". The readings listed below are obtained with the micrometer microscope. Should the reading 2.51 mm be rejected?



Height in mm	$x$	$x^2 \times 10^4$
2.34	-0.026	6.76
2.38	+0.014	1.96
2.40	+0.034	11.56
2.31	-0.056	31.36
2.39	+0.024	5.76
2.29	-0.076	57.76
2.34	-0.026	6.76
2.51	+0.144	207.36
2.37	+0.004	0.16
2.33	-0.036	12.96
		<hr/> 342.40

$$\bar{X} = 2.366$$

$$r = 0.67 \sqrt{\frac{\sum x^2}{N}} = 0.67 \sqrt{\frac{3.42 \times 10^{-2}}{10}} = 0.039$$

For the suspected observation the deviation from the mean is 0.144 and the ratio  $x/r$  is

$$\frac{x}{r} = \frac{0.144}{0.039} = 4.1$$

The tabulated value of  $x/r$  for ten observations is 2.9. Since 4.1 is greater than 2.9, the reading 2.51 should be rejected.

The experimenter may sometimes be hesitant in rejecting an observation by means of this criterion, particularly in borderline cases. The effect of an abnormal observation can to some extent be overcome by increasing the number of readings. Indiscriminate repetition of the experiment, however, will not comparably increase the precision. A law of diminishing returns is in operation, since the precision indices,  $r$  and  $\sigma$ , vary as the square root of  $N$ . Thus, to change one of these indices by one decimal point, it is necessary to multiply  $N$  by 100. (A study of a graph of  $r$  against  $N$  will show that it is usually not profitable to make more than 10 observations by a given experimental method.) It is more profitable to change the method than to repeat the experiment a great number of times.<sup>5</sup>

## 9. PROBABLE ERROR IN COMPUTED RESULTS

If the probable errors of separate independent variables are known and these variables are to be used in a chemical or physical formula, it is necessary to determine the probable error of the dependent variable. Thus, in the expression  $v = \frac{s}{t}$  where  $v$ ,  $s$ , and  $t$  are speed, distance, and time, respectively, we should like to know the probable errors in  $s$  and  $t$ . More generally, if  $Z = f(X, Y, W, \dots)$ , we should like to know the probable error in  $Z$  due to known probable errors in  $X$ ,  $Y$ ,  $W$ , . . . . The probable error is given by the Gaussian theory of errors as

$$R = \pm \sqrt{\left(\frac{\partial Z}{\partial X}\right)^2 r_X^2 + \left(\frac{\partial Z}{\partial Y}\right)^2 r_Y^2 + \left(\frac{\partial Z}{\partial W}\right)^2 r_W^2 + \dots}, \quad (10)$$



where  $R$  is the probable error in  $Z$ , and  $r_X, r_Y$ , etc. are the respective probable errors in  $X, Y$ , etc.

Applying equation (10) to some simple cases, the following formulas are found.

$$1. Z = X \pm Y \quad R = \pm \sqrt{r_X^2 + r_Y^2} \quad (11)$$

$$2. Z = XY \quad R = \pm \sqrt{(Xr_Y)^2 + (Yr_X)^2} \quad (12)$$

$$3. Z = X/Y \quad R = \pm \frac{1}{Y^2} \sqrt{(Xr_Y)^2 + (Yr_X)^2} \quad (13)$$

**EXAMPLE 1.** A speeding automobile is clocked over a measured mile on a highway in 1 minute 20.8 seconds. It is known from experiments that the probable error in measuring the time is  $\pm 3.5$  seconds and the probable error in the distance is  $\pm 25$  yards. Compute the speed of the car and its probable error.

We substitute  $s = 5280$  ft and  $t = 80.8$  sec in the relation

$$v = \frac{s}{t};$$

thus

$$v = \frac{5280}{80.8} = 65.3 \text{ fps}$$

or

$$v = 44.5 \text{ mph.}$$

The probable error in  $v$  will then be given by equation (13); thus

$$R = \pm \frac{1}{t^2} \sqrt{t^2 r_s^2 + s^2 r_t^2}$$

where  $r_s$  and  $r_t$  are the probable errors in  $s$  and  $t$ , respectively.

Since  $r_s = \pm 75$  ft, and  $r_t = \pm 3.5$  sec, we have on substitution

$$R = \pm \frac{1}{(80.8)^2} \sqrt{(80.8 \times 75)^2 + (5280 \times 3.5)^2}$$

and

$$R = \pm 3.0 \text{ fps,}$$

or, in mph,

$$R = \pm 2.0.$$

Hence our result may be written as

$$v = 44.5 \pm 2.0 \text{ mph.}$$

If the legal speed limit is 45 mph on the highway in question, no conclusion can be safely drawn concerning the legality of the speed in question.

**EXAMPLE 2.** At the scene of a motor vehicle homicide a skidmark is measured and found to have a mean length of 96.7 ft with a probable error of  $\pm 3.5$  ft. A series of skidmarks is made in test runs with the vehicle in question. A mean value of 20.5 mph is obtained for the speed in these tests with a probable error of  $\pm 2.0$  mph. If the mean value of the length of the test skidmarks is 15.8 ft with a probable error of  $\pm 1.8$ , compute the probable error in calculating the speed of the car in producing the original skidmark by means of the formula:

$$v_1 = v_2 \sqrt{\frac{s_1}{s_2}}$$

where  $v_1$  is the speed in question;  $s_1$  is the length of the skidmark at the scene; and  $v_2$  and  $s_2$  refer, respectively, to the speed and skidmark length of the test runs. The skidmark length is measured in feet and the speed in mph.



Applying equation (10) to function  $v_1$ , we have

$$R_{v_1} = \pm \sqrt{\left(\frac{\partial v_1}{\partial v_2}\right)^2 r_{v_2}^2 + \left(\frac{\partial v_1}{\partial s_1}\right)^2 r_{s_1}^2 + \left(\frac{\partial v_1}{\partial s_2}\right)^2 r_{s_2}^2}$$

On substituting the following values:

$$\frac{\partial v_1}{\partial v_2} = \sqrt{\frac{s_1}{s_2}}; \frac{\partial v_1}{\partial s_1} = \frac{v_2}{2\sqrt{s_1 s_2}}; \frac{\partial v_1}{\partial s_2} = \frac{-v_2 \sqrt{s_1}}{2s_2 \sqrt{s_2}}$$

our equation becomes

$$R_{v_1} = \pm \sqrt{\frac{s_1}{s_2} r_{v_2}^2 + \frac{v_2^2}{4s_1 s_2} r_{s_1}^2 + \frac{v_2^2}{4s_2^3} s_1 r_{s_2}^2}$$

Since

$$s_1 = 96.7; s_2 = 15.8; v_2 = 20.5; r_{v_2} = 2.0; r_{s_1} = 3.5; \text{ and } r_{s_2} = 1.8,$$

we have

$$R_{v_1} = \pm \sqrt{\frac{97 \times 4}{16} + \frac{(20 \times 3.5)^2}{4 \times 97 \times 16} + \frac{(20 \times 1.8)^2 \times 97}{4 \times 16^3}};$$

or

$$R_{v_1} = \pm 5.7.$$

Computing  $v_1$  from

$$v_1 = v_2 \sqrt{\frac{s_1}{s_2}}$$

we have

$$v_1 = 20.5 \sqrt{\frac{96.7}{15.8}} = 50.7 \text{ mph}$$

and

$$v_1 = 50.7 \pm 5.7 \text{ mph.}$$

If the legal speed limit is 40 mph, we can conclude that the driver of the vehicle was exceeding that limit at the time of the collision. However, if the speed limit is 45 mph we should hesitate to draw such a definite conclusion in view of our probable error of 5.7 mph. (In practice the large errors used in this example are not ordinarily found).

## 10. LIST OF FORMULAS

$\bar{X} = \frac{\Sigma X}{N}$	Mean for a series of measurements
$\sigma = \sqrt{\frac{\Sigma x^2}{N}}$	Standard deviation
$\bar{\sigma} = \frac{\sqrt{\Sigma x^2}}{N}$	Standard error of the mean
$r = \pm 0.67 \sqrt{\frac{\Sigma x^2}{N}}$	Probable error
$\bar{r} = \pm 0.67 \frac{\sqrt{\Sigma x^2}}{N}$	Probable error of the mean
$R = \pm \sqrt{r_X^2 + r_Y^2}$	Probable error of the sum or difference of two variables
$R = \pm \sqrt{(Xr_Y)^2 + (Yr_X)^2}$	Probable error of the product of two variables



## EXERCISES

1. A glass fragment (A) found on the clothing of a suspected burglar is compared with a fragment (B) taken from a broken pane at the scene of the crime. In measuring the refractive index, the following observations are obtained for the samples: Sample A — 1.413, 1.420, 1.418, 1.411, 1.408, 1.419, 1.414, 1.418, 1.413, 1.415; Sample B — 1.410, 1.415, 1.411, 1.408, 1.413, 1.412, 1.414, 1.409, 1.409, 1.416. Does a statistically reliable difference exist between the values obtained for the refractive indices of these specimens?

2. In a motor vehicle homicide the length of a skidmark,  $s$ , is found to be 118 ft. The coefficient of friction,  $\mu$ , between the tires and the roadway is found to be 0.62. If the estimated error in  $s$  is  $\pm 4$  and in  $\mu$  is  $\pm 0.1$ , approximate the error in  $v$ , the speed in mph.  $v$  is determined by the equation:

$$v = \sqrt{30\mu s}$$

3. In determining the speed of a vehicle from the skidmark found at the scene of a certain accident the maximum error in measuring this mark is assumed to be  $\pm 10$  per cent. Using the same car, skidmarks are produced for comparison. It is assumed that the error in measuring these latter marks may be as much as  $\pm 6$  per cent. The error in the speedometer is taken as  $\pm 5$  per cent. What is the approximate error in computing  $v_1$  from the formula  $v_1 = v_2 \sqrt{s_1/s_2}$ ?

4. In the course of a ballistics investigation it is found necessary to compute the height of a tower situated on the top of a hill. Observations are taken from the foot of the hill. The angle of elevation to the base of the tower is  $25^\circ$  and to the top,  $39^\circ$ . The measurements are accurate to  $\pm 25''$ . The distance from the base of the tower to the point of observation is  $280.4 \pm 0.3$  ft. Determine the height of the tower and the probable error of this value.

5. In a handwriting examination the angle of inclination of the  $t$ 's is measured with a protractor. The following readings (in degrees) are obtained: 44, 42, 47, 39, 48, 43, 46, 41, 49. Compute the arithmetic mean, the standard error, and the probable error of the mean.

6. One problem of firearms identification is that of ascertaining the type of gun used to fire a bullet recovered in an assault or homicide case. Assuming that the bullet

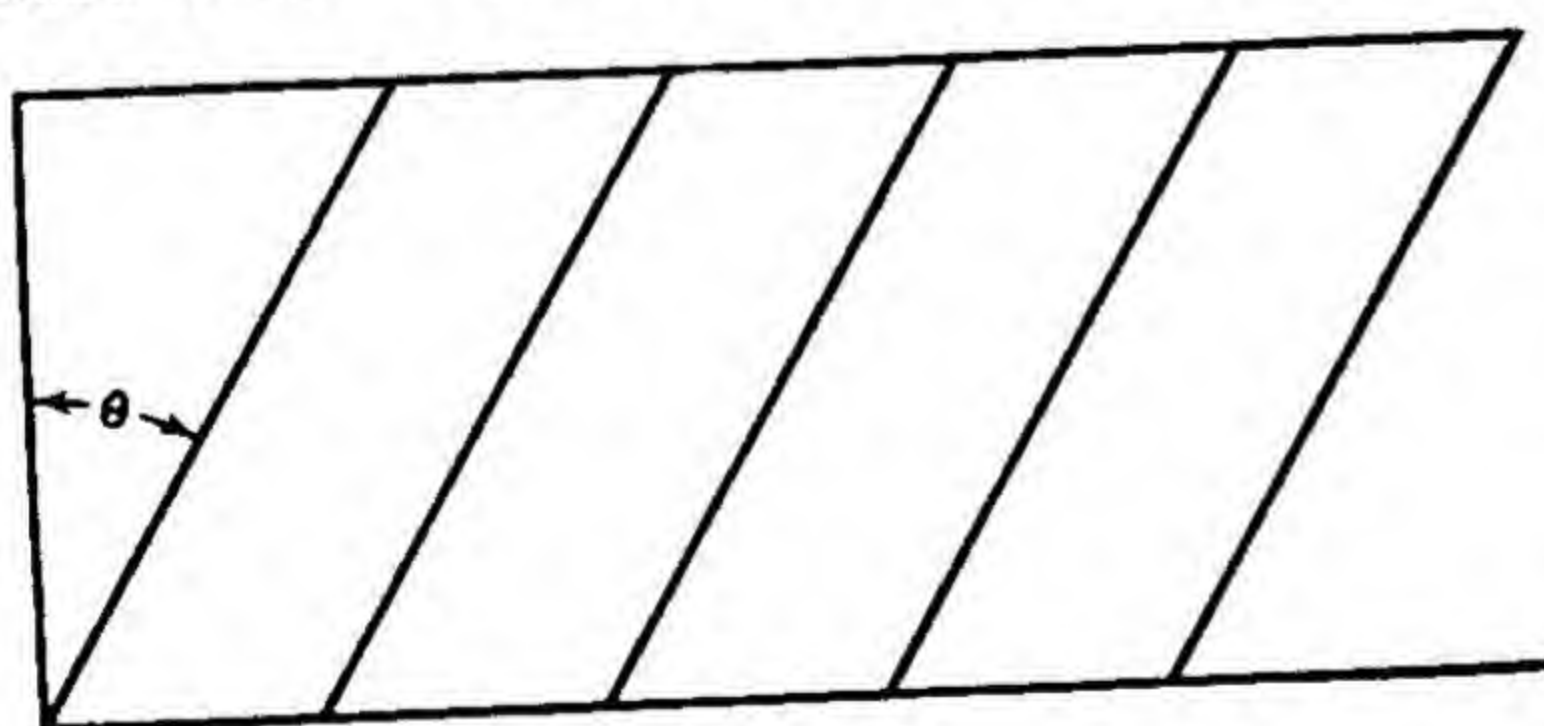


Fig. 23.

has not been greatly deformed, (and disregarding for the moment more practical considerations such as weight, width of lands and grooves, direction of rifling, etc.), what effect has an error in the pitch, as determined from a pantoscopic photograph of the surface of the bullet (or from a photograph of an impression of the surface rolled out on cellulose

acetate using the method of Moritz), upon the identification of the gun from the bullet? Fig. 23 is a schematic diagram of the surface of a bullet impressed on a plane. It is easily shown that the formula used to calculate the pitch,  $P$ , is  $P = B \tan \theta$ , where  $B$  is the circumference of the bullet and  $\theta$  is the angle of twist. Derive a formula for the probable error in the pitch due to probable errors in the circumference and angle of twist.

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# CHAPTER 6

## MEASURING INSTRUMENTS

### 1. VERNIER AND MICROMETER CALIPERS

#### The Measurement of Length

Perhaps the most common of physical laboratory measurements is that of length. The two basic instruments for this measure are the vernier and micrometer calipers. In this section the principle of the micrometer screw and the vernier are treated. These devices will be found on many other instruments which will be used in the laboratory.

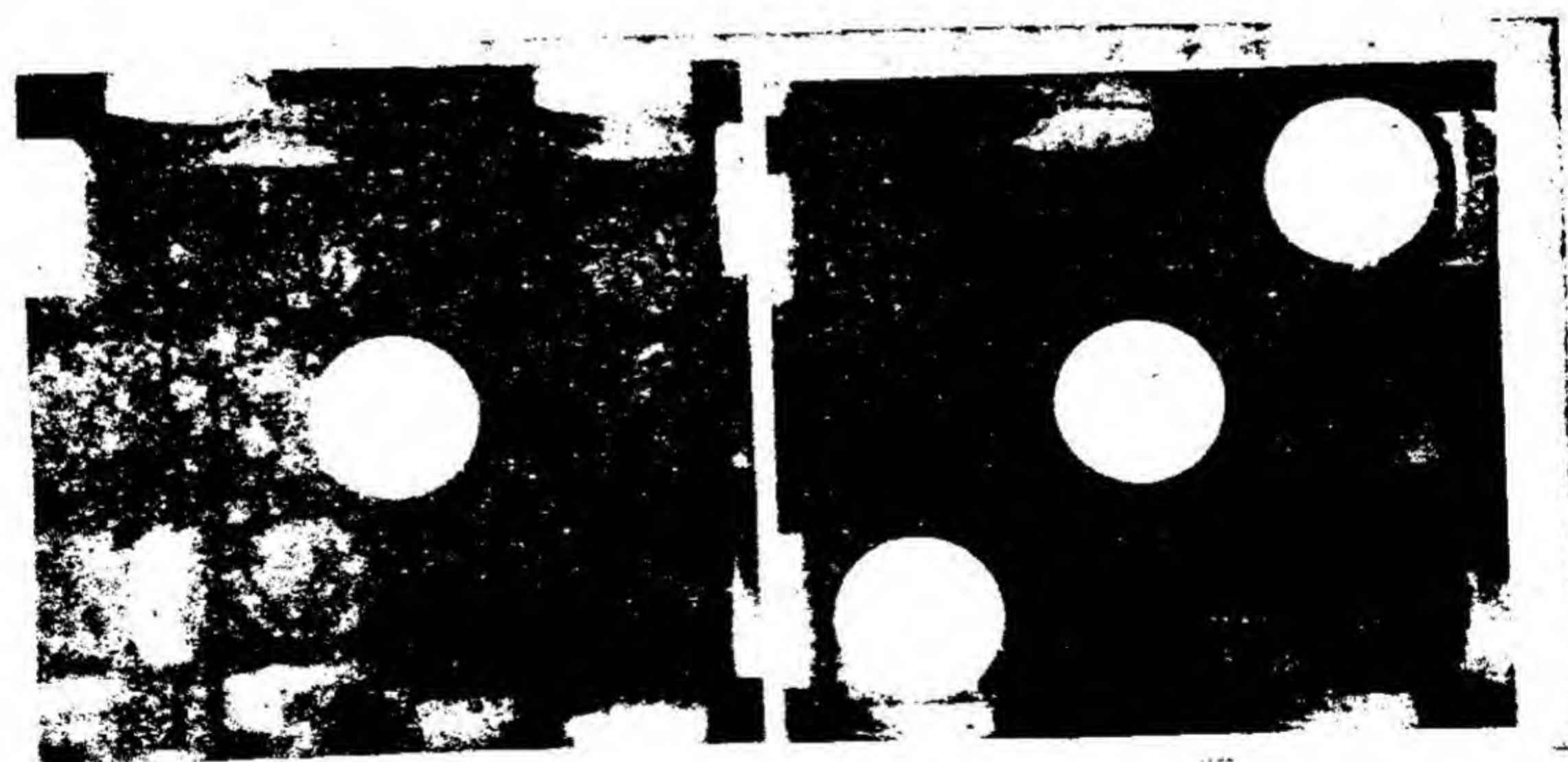


Fig. 24. A case involving measurements — one side of the left die is slightly longer than the other.

In many cases where two fragments are being compared to determine whether they were originally parts of the same object, the dimensions of the pieces may be the deciding factors. For example, in the examination of a piece of wire alleged to have been snipped from another piece, the diameter or gauge would be important. Similarly, a pair of dice alleged to be altered, or playing cards which have been "shaved" must be measured with precision to detect small differences. Figure 24 illustrates a case involving such a measurement of altered dice. In comparing the tool marks on a surface with the jimmy, crowbar,



or other instrument used to make these marks, the distance between significant marks should be carefully measured with relation to the corresponding marks on the tool (in addition, of course, to the usual photographs).

It is well, as a matter of regular procedure, to take measurements of the significant dimensions of all physical objects submitted in evidence, such as broken automobile parts, shoes, and plaster casts, etc. These measurements may aid later in identifying the object. Usually, testimony concerning the evidence is not given in court until months after the examination; unless the investigator has recorded the measurements of the object in question or has photographed it with a ruler in the field, his mental picture of the object will be quite hazy. Moreover, the expert witness is frequently asked to state the length or width of an object, although these measurements may have no relation to the point at issue.

### The Principle of the Vernier

In the precision measurement of length many instruments utilize the principle of the vernier. Essentially the vernier is a short auxiliary scale (starred scale

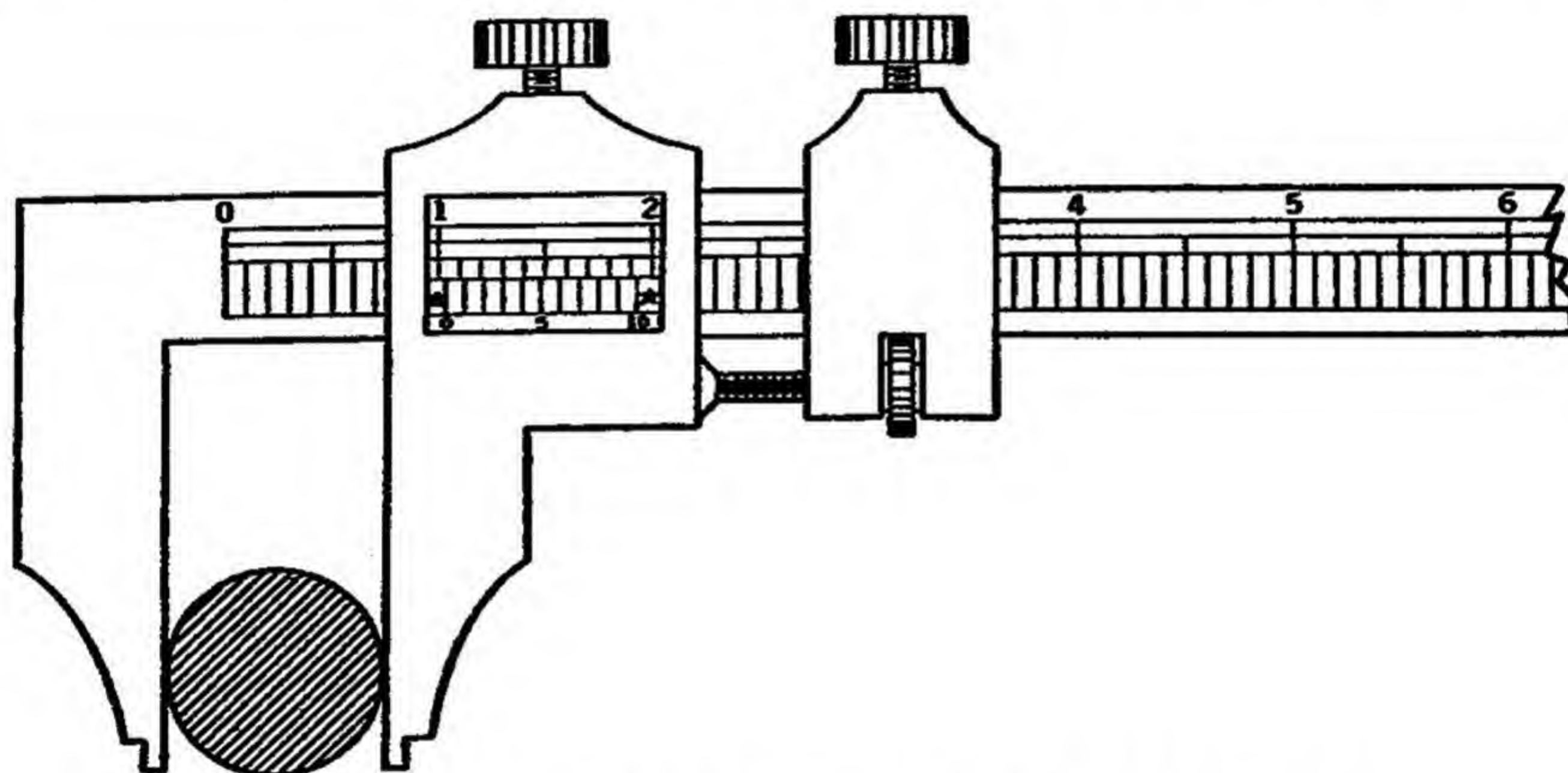


Fig. 25. Illustrating the principle of the vernier.

in Fig. 25) which makes it possible to read more accurately fractions of a division of the main scale. The most common type of vernier is described below. If the vernier scale has  $n$  divisions, it will, when laid along the main scale, cover  $(n - 1)$  divisions of this main scale. Ordinarily the vernier has 10 divisions. Hence, one division of the vernier is  $9/10$  the length of one division of the main scale. If, for example, in measuring an object it is found that the end of the object lies between the 1.0 and the 1.1 marks on the main scale (Fig. 25), the zero mark of the vernier is placed at the end of the object while the vernier lies along the main scale. A mark of the vernier will be found to coincide approximately with *some* mark on the main scale. This mark of the vernier determines the complete measurement; e.g., if the third mark of the vernier coincides with a mark of the main scale, the reading is 1.03. The reason for this is readily seen. Since the third mark of the vernier coincides with a mark on the main scale, and, since



each vernier division is 0.1 short of being a main scale division, the second mark of the vernier is 0.1 of a main scale division short of coinciding with the nearest mark on the main scale. The first mark of the vernier is 0.2 of a scale division beyond its corresponding scale line, and the zero mark is, consequently, 0.3 of a scale division beyond the corresponding scale line which in this case is 1.

Let  $n$  be the number of divisions on the vernier and  $V$  the length of a vernier division. The number of main scale divisions is  $(n - 1)$ , and the length of a main scale division is  $S$ . It is evident that

$$nV = (n - 1)S$$

and that

$$S - V = \frac{1}{n} S$$

The quantity  $S - V$ , the difference between a main scale division and a vernier division, is called the *least-count* of the instrument. The least-count of the instrument is an indication of the fineness of measurement obtainable with the instrument.

### The Vernier Caliper

The vernier caliper (Fig. 26) consists essentially of a straight scale with a fixed jaw to which is attached a movable jaw and vernier. The object to be

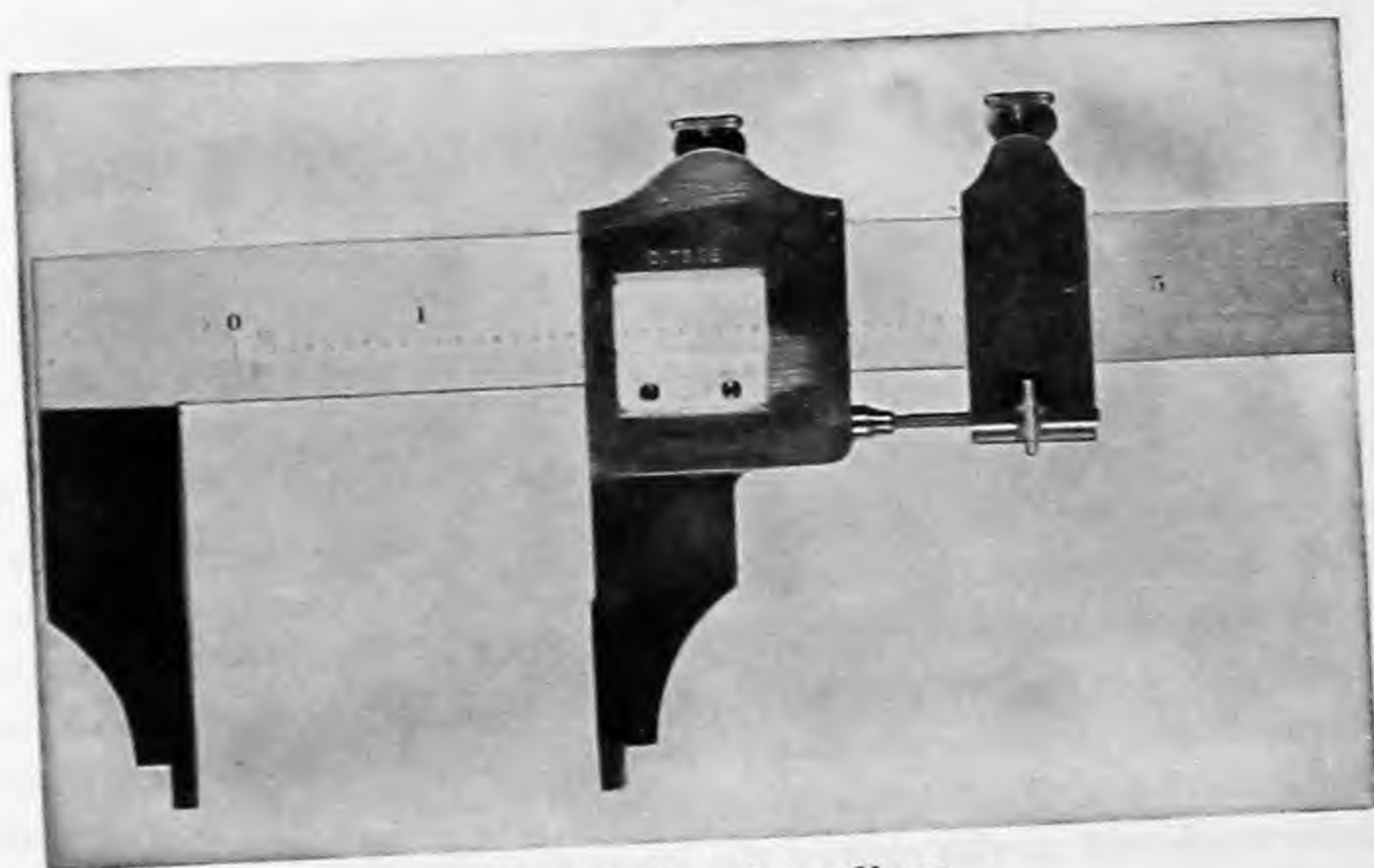


Fig. 26. Vernier caliper.

measured is placed within the jaws, which are then tightened. The mark on the main scale before the zero of the vernier, which is the index, is noted, and then the line of coincidence is observed for the complete reading.



### The Micrometer Caliper

The micrometer caliper (Fig. 27) has a curved frame, one end of which serves as a fixed jaw, and a screw which serves as a movable jaw. The screw is equipped with a circular scale and travels along a longitudinal scale. The circular scale determines fractional parts of the longitudinal scale divisions. In some instruments the longitudinal scale is divided into millimeter divisions and the circular scale is marked into 50 divisions. Since it requires two revolutions

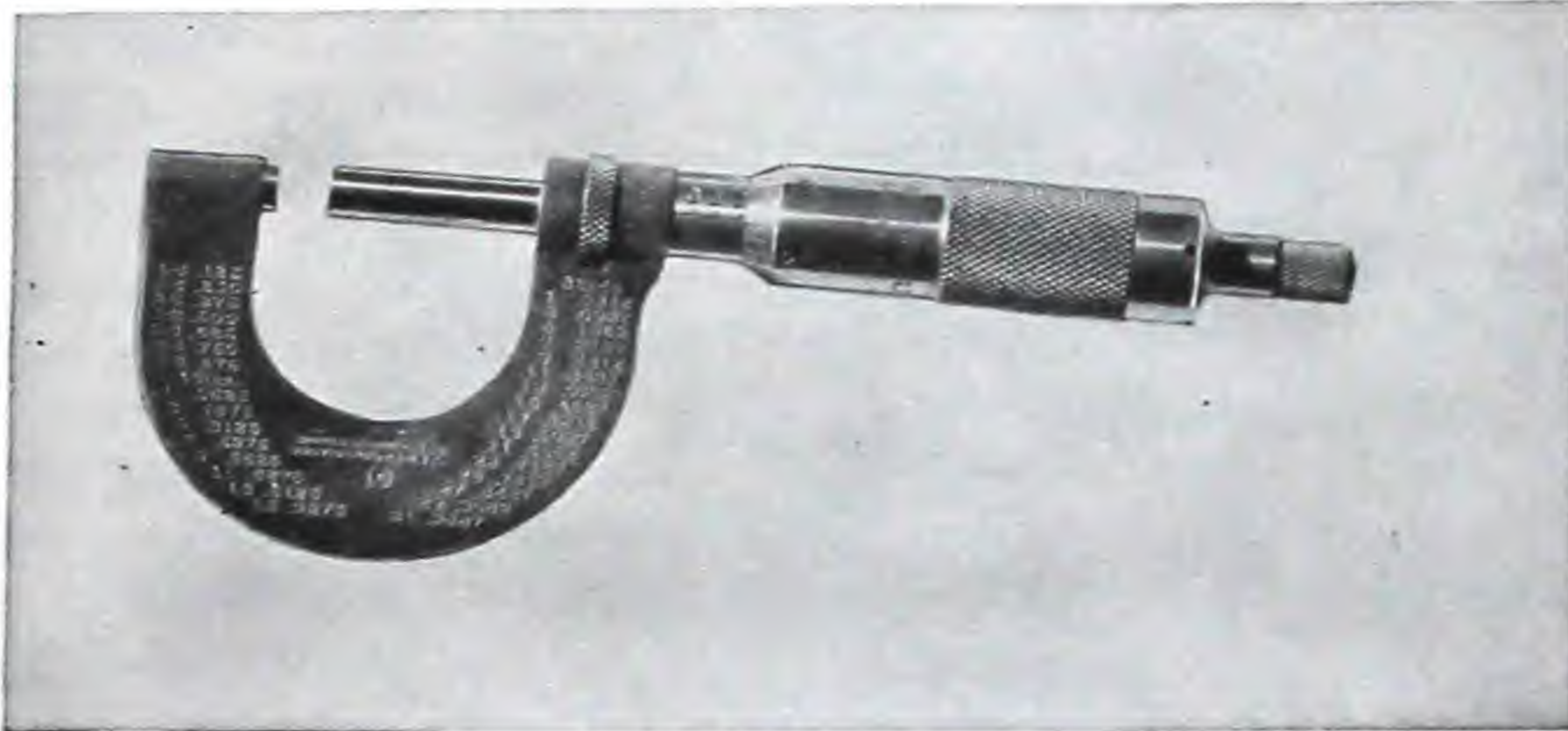


Fig. 27. Micrometer caliper.

of the circular scale to move the edge of the screw (which is the index) one millimeter along the longitudinal scale, each division of the circular scale corresponds to 0.01 millimeter. The instrument illustrated in Fig. 27 is calibrated in fractions of an inch. A measurement is made by placing an object between the jaws of the caliper and turning the screw by the *small auxiliary handle* until contact is made. This is indicated by the distinct clicks of a ratchet. Sufficient pressure is had when approximately three clicks are heard.

## 2. RADIUS OF CURVATURE OF GLASS LENSES AND OTHER CURVED SPECIMENS

The curvature of an object may become an important measurement in some investigations. For example, suppose that in a case involving two pieces of metal it is desired to establish that they were parts of the same piece of machinery; or, in the case of two pieces of spectacle glass found at the scene of a crime, that they were parts of the same lens. Fragments of broken bottles in assault cases sometimes present the same problem. Obviously, if the two broken pieces had been adjacent, excellent proof is had by merely showing the "fit," as in a jig-saw puzzle. If, however, the parts had not been contiguous, measurements may be needed to show the common source.

When the pieces in question are parts of a surface of revolution such as a cylinder or a sphere, the radius of curvature becomes a significant measurement.



A cylindrical handle of a tool or a spherical lens would require such a measurement under certain circumstances. Two standard instruments, the spherometer and the Geneva gauge, which are used for determining the radius of curvature are studied here.

### The Spherometer

The spherometer consists essentially of a central screw set in a tripodal frame (Fig. 28). The screw is moved by means of a milled head mounted on a graduated disk. The disk moves along a vertical scale. The principle of the spherometer is the same as that of the micrometer caliper; the movable scale serves as an index for the main scale, and also divides the smallest division of the main scale into at least as many subdivisions as are indicated on the movable scale itself. The spherometer can be used to measure with precision small vertical distances above and below the plane of the points of the three legs.

By plane geometry it can be shown that the radius of a circle which is cut into segments by a perpendicular chord is given by the following equation:

$$R = \frac{h^2}{2L} + \frac{L}{2} \quad (1)$$

where  $R$  is the radius,  $h$  is one-half the length of the chord, and  $L$  is the length of the outer segment. To understand the geometry involved, consider  $R$  to be the radius of a great circle perpendicular to the plane of the three leg-points. Equation (1) is applied in measuring the radius of curvature of a surface. In this case,  $h$  is the distance from any leg of the spherometer to the point of the screw when all are in the same plane, and  $L$  is the distance moved by the screw. The reader is referred to Chapter 24 for the derivation of equation (1).

### The Geneva Gauge

Another instrument for determining the curvature of a spherical surface is the Geneva gauge or "clock" (Fig. 29). This instrument is pressed lightly against the surface which is being examined until the three legs are in contact with the surface. The middle or movable leg causes an indicator to revolve on the dial, giving a measurement in diopters. The Geneva gauge is especially useful in calculating the diameter of a circular automobile lens where only a fragment of the edge is present. The advantage of the gauge over the spherometer for this work lies in the position of the legs: in the Geneva gauge the legs lie

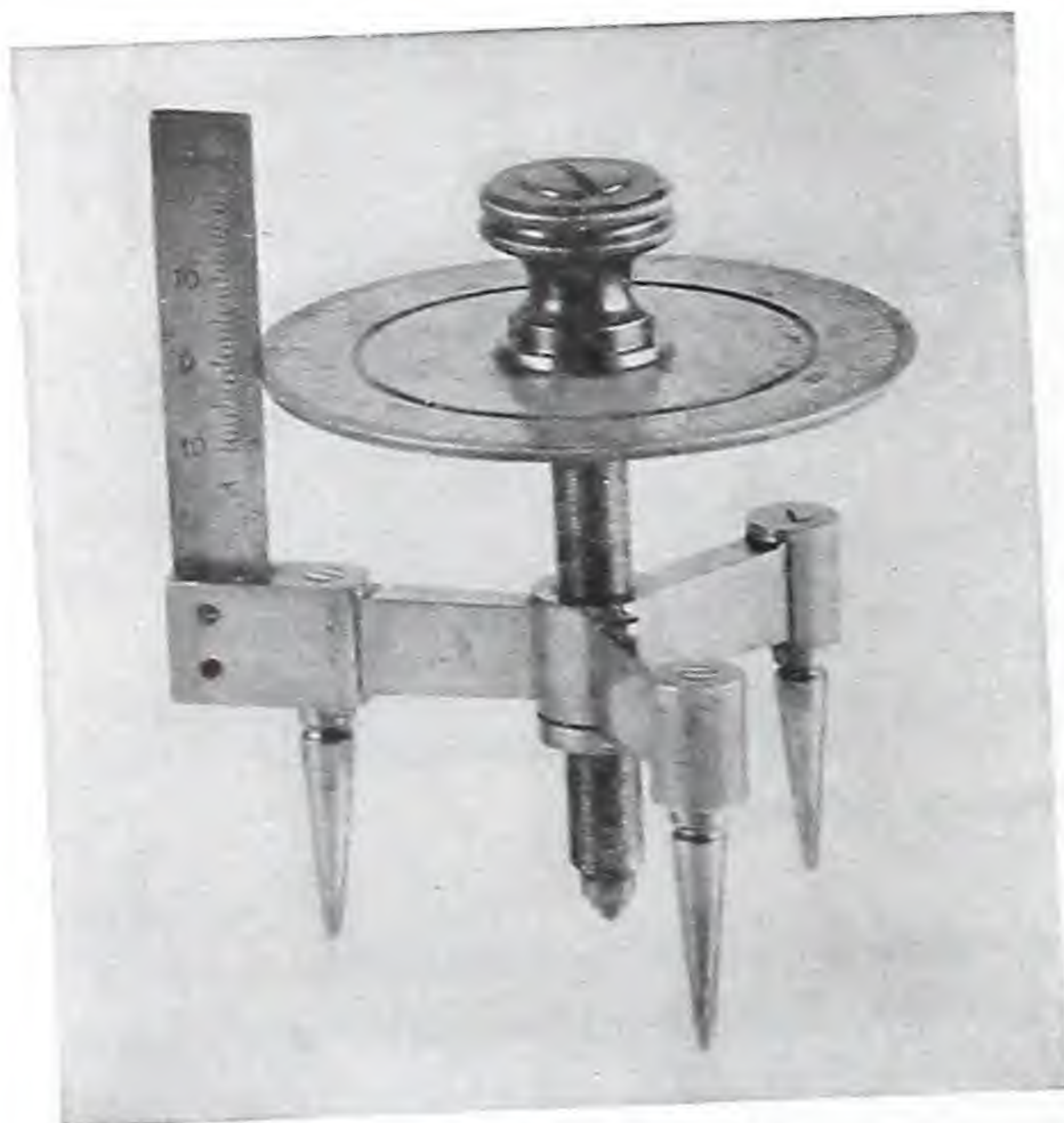


Fig. 28. Spherometer.



in a straight line; in the spherometer they do not lie in a straight line. Thus it is possible to apply the gauge to a rim which would be too narrow for the use of the spherometer.

The Geneva gauge is specifically designed for the purposes of opticians. It is calibrated to interpret the radius of a surface in terms of diopters for glass of a

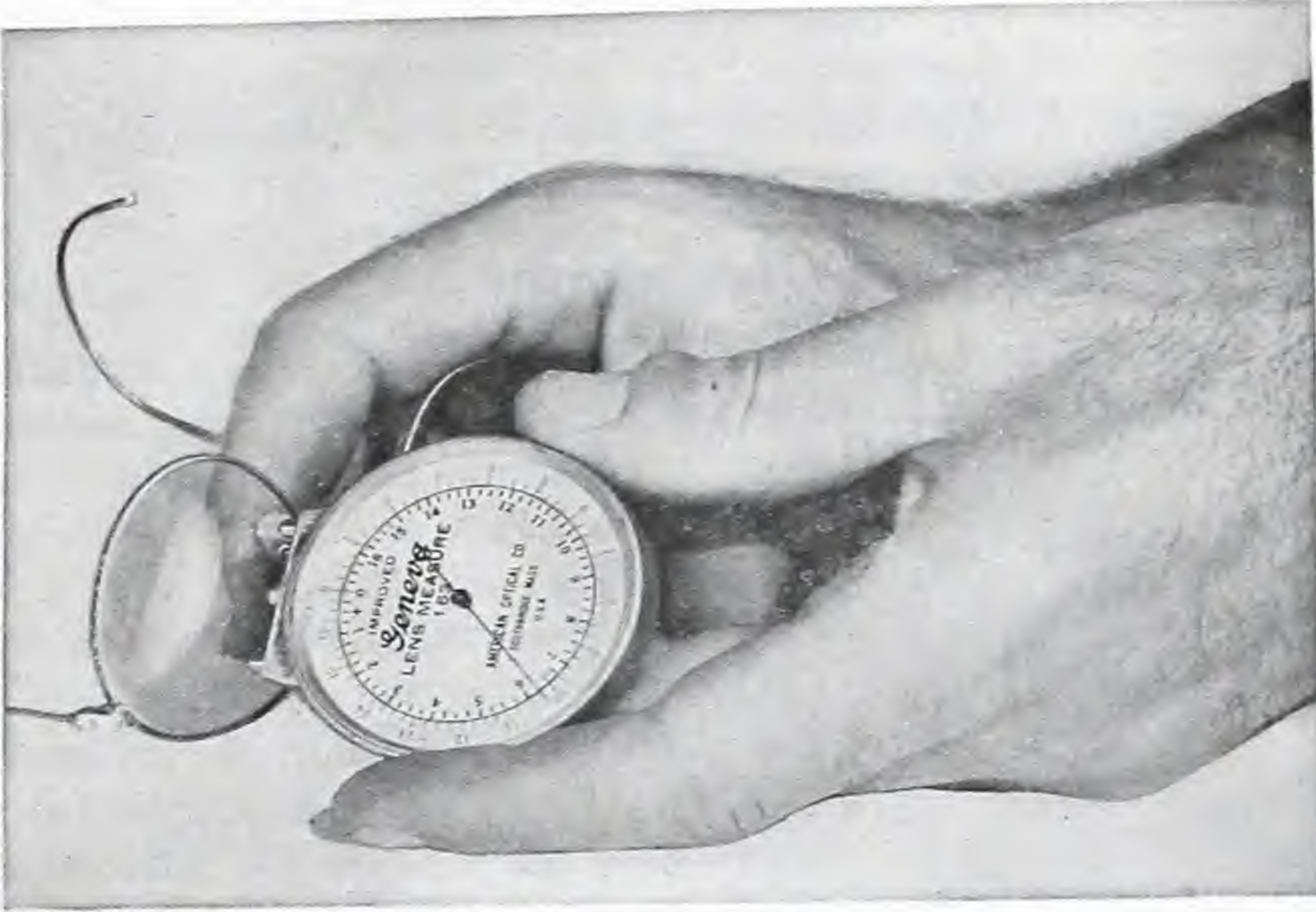


Fig. 29. Geneva Gauge.

specific index of refraction. (This is called the *power* of the lens.) For our purposes we must interpret the diopters reading in terms of the diameter.

The power of a lens in diopters is equal to the reciprocal of the focal length expressed in meters. If  $P$  is the power and  $F$  the focal length we have

$$P = \frac{1}{F} \quad (2)$$

From the general lens equation we know that, where  $R_1$  and  $R_2$  are the radii of curvature and  $n$  is the index of refraction,

$$\frac{1}{F} = (n - 1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right)$$

We can simplify this by assuming a planoconvex or planoconcave surface in which case  $R_2 = \infty$  and the equation becomes

$$R = (n - 1)F \quad (3)$$

where  $R$  is now the radius of curvature of the surface in question. Substituting from equation (2), we have

$$R = \frac{n - 1}{P}$$



Since the gauge is calibrated for an index of refraction of 1.530, we have, for converting the power reading into inches, the expression:

$$R = \frac{0.53 \times 39.37}{P}$$

Usually the diameter  $D$  is of greater interest than the radius; hence

$$D = \frac{41.7}{P} \quad (4)$$

In other words, by dividing the scale reading  $P$  of the gauge into 41.7 we obtain the value of the diameter of the curved surface in terms of inches.

### 3. THE MICROMETER MICROSCOPE

In many types of investigation it is necessary to measure small distances with considerable accuracy; for example, in handwriting and typewriting comparisons, and in comparisons of small tool marks fine measurements are important. In a small laboratory, where one microscope must serve for all purposes, these measurements can be accomplished by the use of a micrometer eyepiece with this microscope. In a fairly large laboratory it is more practical to have one instrument set aside for routine micrometry. A micrometer microscope for this purpose is illustrated in Fig. 30. It is well to learn the use of this instrument at this point because of the elementary nature of the measurement.



Fig. 30. Micrometer eyepiece and microscope.

The distance directly measured with the micrometer microscope is not that between two points on the subject, but that between two points in an enlarged image of the object. The scales of measurement are calibrated to give the reading of the actual distance.

The micrometer microscope consists of a long tube in the lower end of which is fixed a lens called the *objective*; telescoped into the upper end is a short tube with a combination of lenses called the *eyepiece*. The objective produces an enlarged image of the object in the plane of a set of cross hairs. The eyepiece is focused on the plane of the cross hairs. The cross hairs may be moved across the image of the object by turning a fine screw, which is equipped with a graduated torsion head. To use the instrument practically, we must be able to determine the actual distance traversed on the object when the cross hairs have traveled between two points on the image; that is, we must determine the equivalent in centimeters (or inches) of one division on the torsion head. To accomplish this,



## MEASURING INSTRUMENTS

The hairlines are moved between two points on a stage micrometer scale, and the number of turns of the torsion head required to effect this passage is noted. This stage micrometer is a glass slide upon which is ruled a scale of convenient dimensions, such as 2 mm divided into 200 parts. From this, the *calibration constant* is determined, and the instrument may then be used to measure unknown distances.

To focus the eyepiece on the cross hairs, direct the microscope toward a sheet of white paper, and after pulling the eyepiece out as far as possible, move it in until the cross hairs are brought sharply into focus. The eyepiece is not to be touched once it has been focused on the cross hairs; all other focusing is accomplished by manipulation of the objective.

Place the stage scale before the objective in such a position that its rulings are parallel to the moving cross hairs. Raise the objective by turning the screw, at the same time holding the upright support to prevent the instrument from slipping. Bring the scale into focus by lowering the objective slowly. The focus is perfected by eliminating parallax. Parallax is the apparent relative motion between the cross hairs and the image produced by real motion of the eye. (In using a micrometer eyepiece with a high-power objective, the objective is raised to focus to avoid damage through careless lowering. Parallax is avoided by using the fine motion about the point of approximate focus.)

Turn the screw until the movable cross hairs travel the distance between ten or twenty successive lines on the scale, noting the initial and final reading of the torsion head in whole turns and small divisions. It will be seen from this trial that confusion is liable to arise, if there is but one reader, in determining the number of turns. The difficulty is removed by the provision of a serrated scale for purposes of orientation. This scale is located in the plane of the image and cross hairs. In one revolution of the torsion head the cross hairs travel from one tooth to the next. Every fifth tooth is distinguishable by its size. Calculation is facilitated also by turning the screw in that direction which gives increasing numbers on the torsion head. The screw should not change direction during any reading, because this leads to lost motion or backlash. The screw should not be turned too far in any direction. It has gone too far whenever a gap of white shows on either side.

## 4. OTHER MEASURING DEVICES

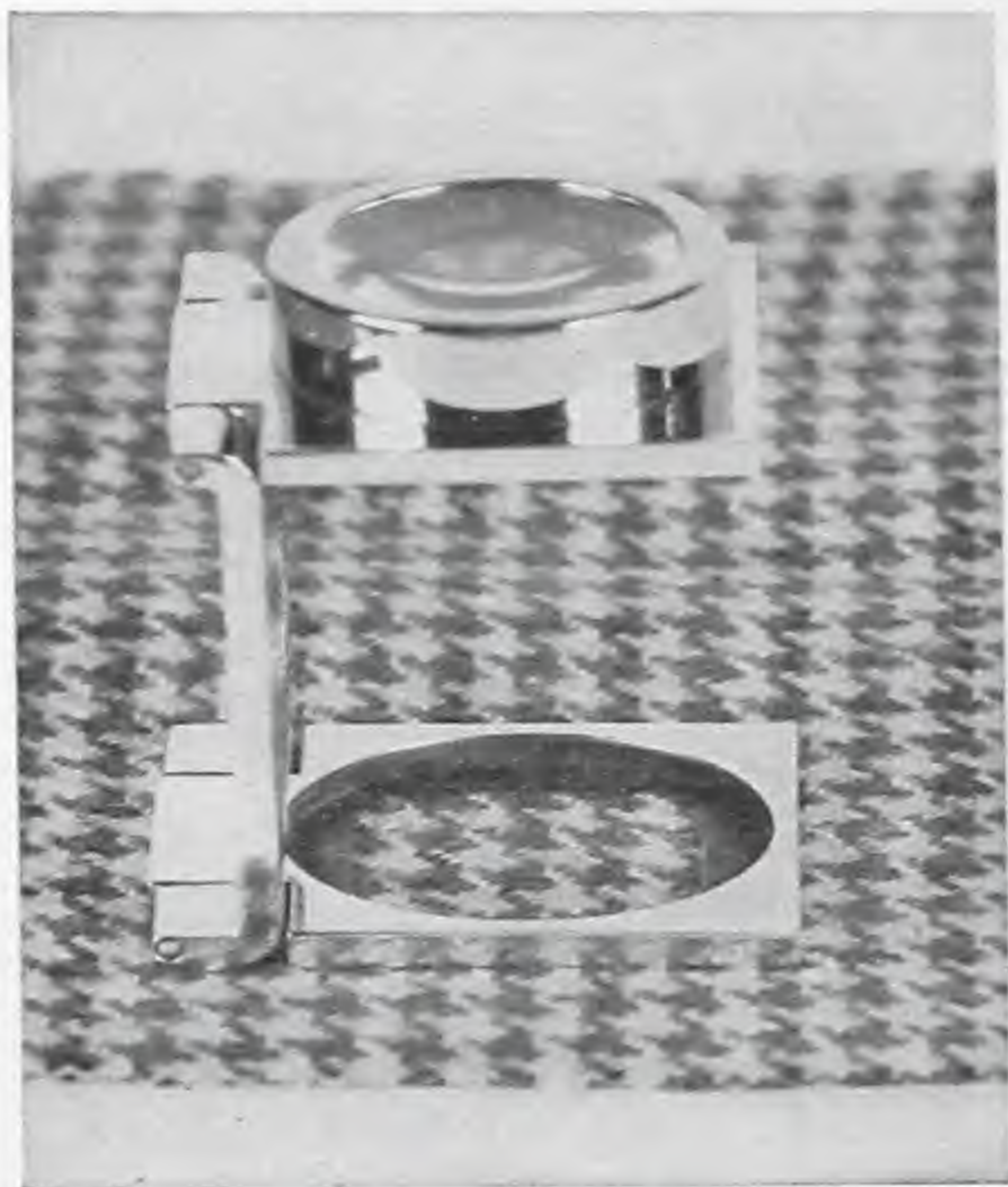
### Thread-Counting Devices

In cases involving a comparison of fabrics or the comparison of a fabric with an impression (see Fig. 179), it is necessary to count the number of yarns or threads per unit length in a given direction. Several devices are available for this purpose.

**Pick Glass** — The pick glass or linen tester consists of a simple magnifying lens set in a folding mount, the base of which is a square aperture of known size. The number of yarns in the field of view is counted.



**Thread-Counting Micrometer** — This instrument (Fig. 32) has the advantage of variable focus and wider range in regard to the length of cloth covered in a given reading. When the eyepiece is focused, a magnified image of a scale, pointer, and the fabric is visible. By means of a knurled disk the lens and pointer are made to move across the field and scale. Each yarn is counted as it crosses the pointer which is moved over a known length.



**Fig. 31. Pick glass or linen tester.**

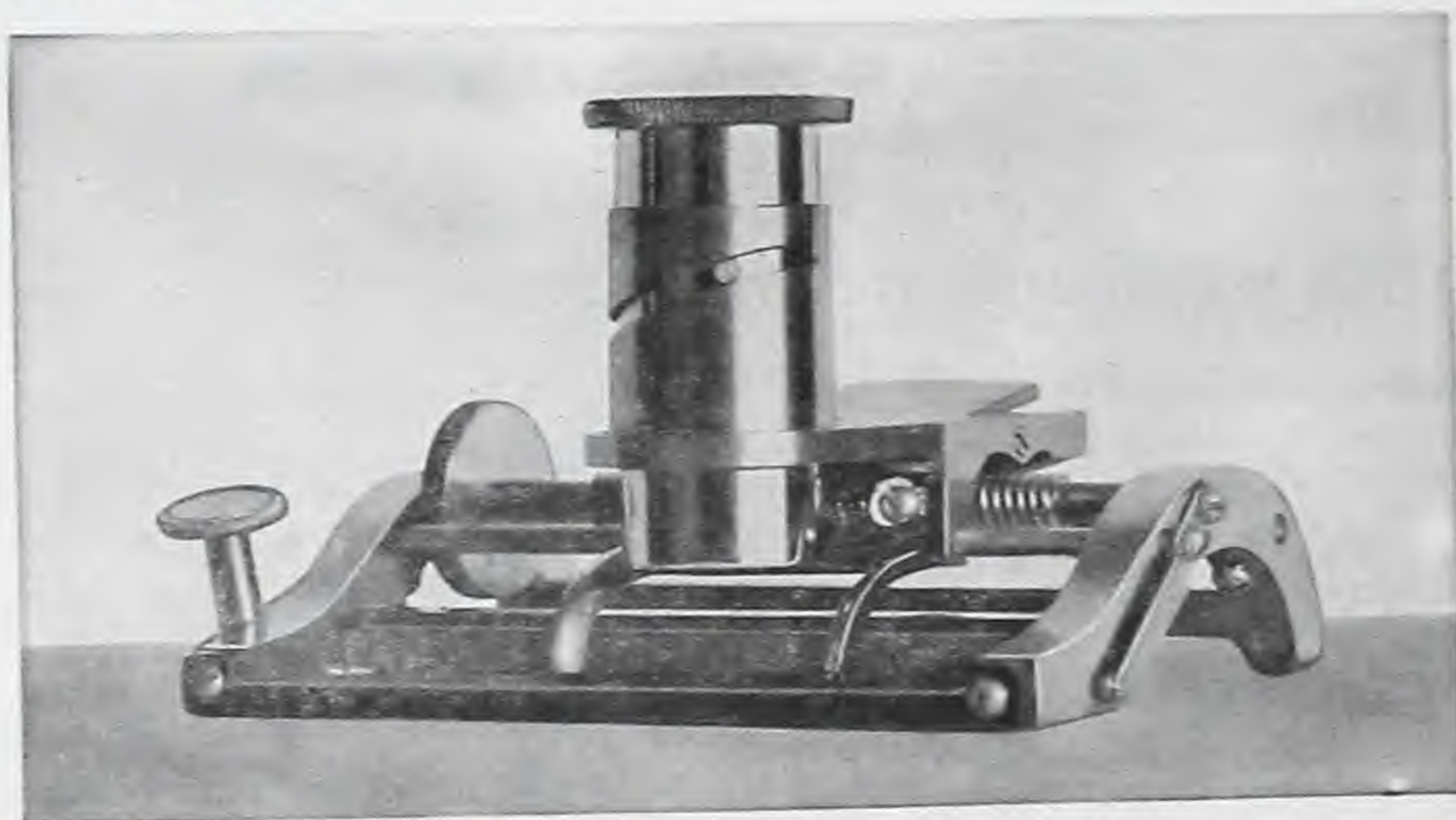
**Microscope** — The micrometer microscope will also serve the purpose here.

### **Paper Gauge**

In a document examination or in a counterfeit money or ticket investigation a comparison of papers is often required. Sometimes the thickness of the paper becomes a significant measurement. A paper gauge will be found useful for this purpose. The gauge can also be applied to the measurement of the thickness of metal, veneer, cloth, cardboard, celluloid, leather, etc. Two common types of gauge are used:

**Dial Gauge** — This may be in the form of the dial bench gauge or the sheet gauge. In both instruments a contact point is raised and released after the sample is inserted. The dial is graduated to read in thousandths of an inch (Fig. 33).

**Paper Gauge Micrometer Caliper** — This instrument is the conventional



**Fig. 32. Thread counting micrometer.**



micrometer caliper with disks approximately  $\frac{1}{2}$  inch in diameter on the anvil and spindle. Measurements can be taken without compressing the articles measured.

### Standard Sieves

In some investigations a measurement of particle size will be of importance; for example, the use of abrasives in a sabotage case may demand particle size measurements. A comparison of sand found in a suspect's shoe with sand from the scene of the crime would be another example. Rubber fillers, paint pigments, seed, sugar, and many other substances can be subjected to this additional physical test.

Dry-mesh analysis is the simplest method of determining particle size. A nested set of standard sieves such as that illustrated in Fig. 34 is used. The mesh size varies with the type of sample to be tested. With sand, for example, screen sizes of 20, 40, 60, 80, and 100 openings per linear inch are used. Finer materials can be measured with sieves of 120, 140, 170, and 200 mesh.

A known weight of the material is placed in the top sieve. The sieves are then shaken with a sideways and up-and-down motion until no further separation occurs. The amounts of material left on each screen and in the pan are then weighed. The percentages retained on each mesh are then calculated.

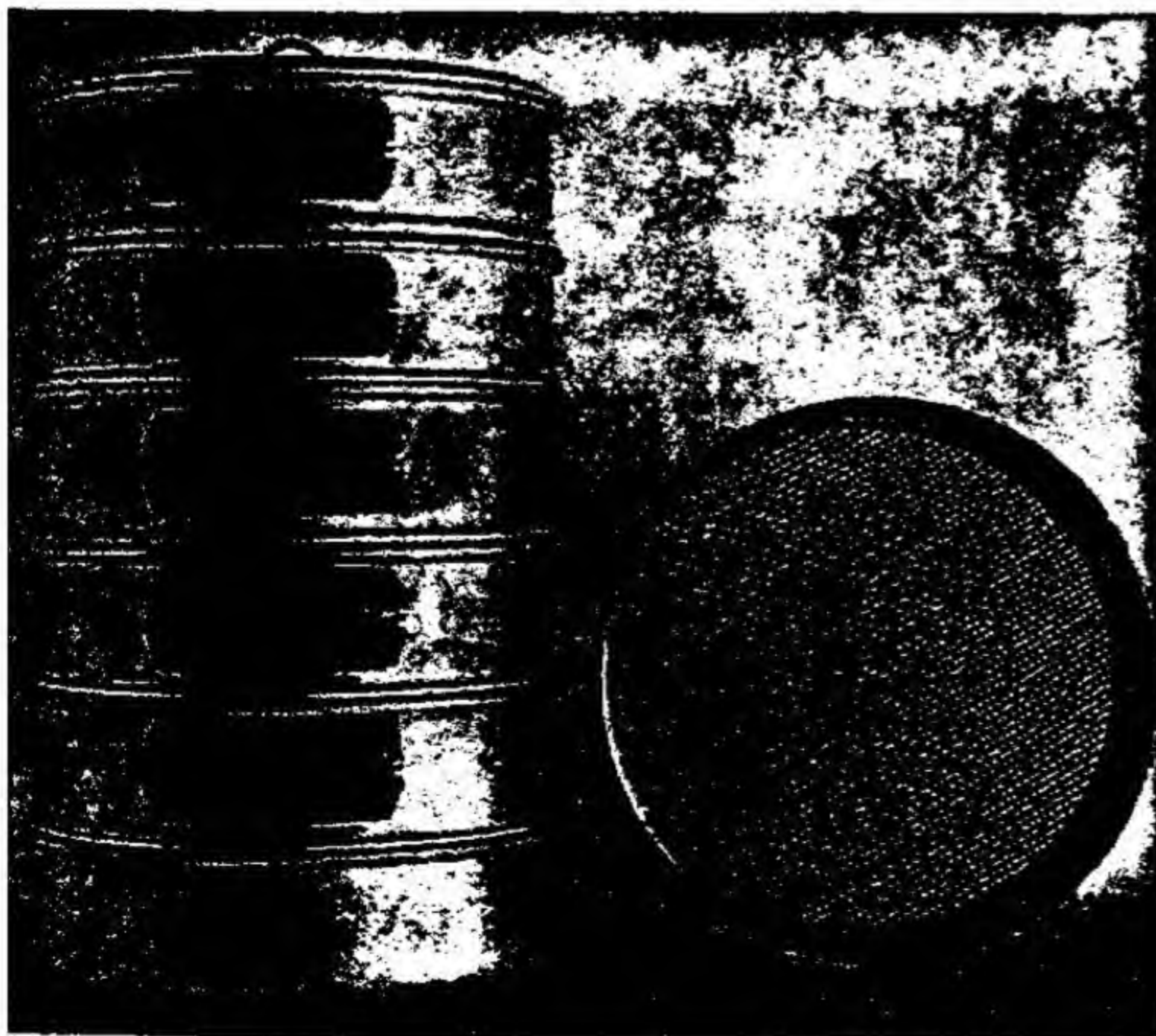


Fig. 34. Standard sieves.

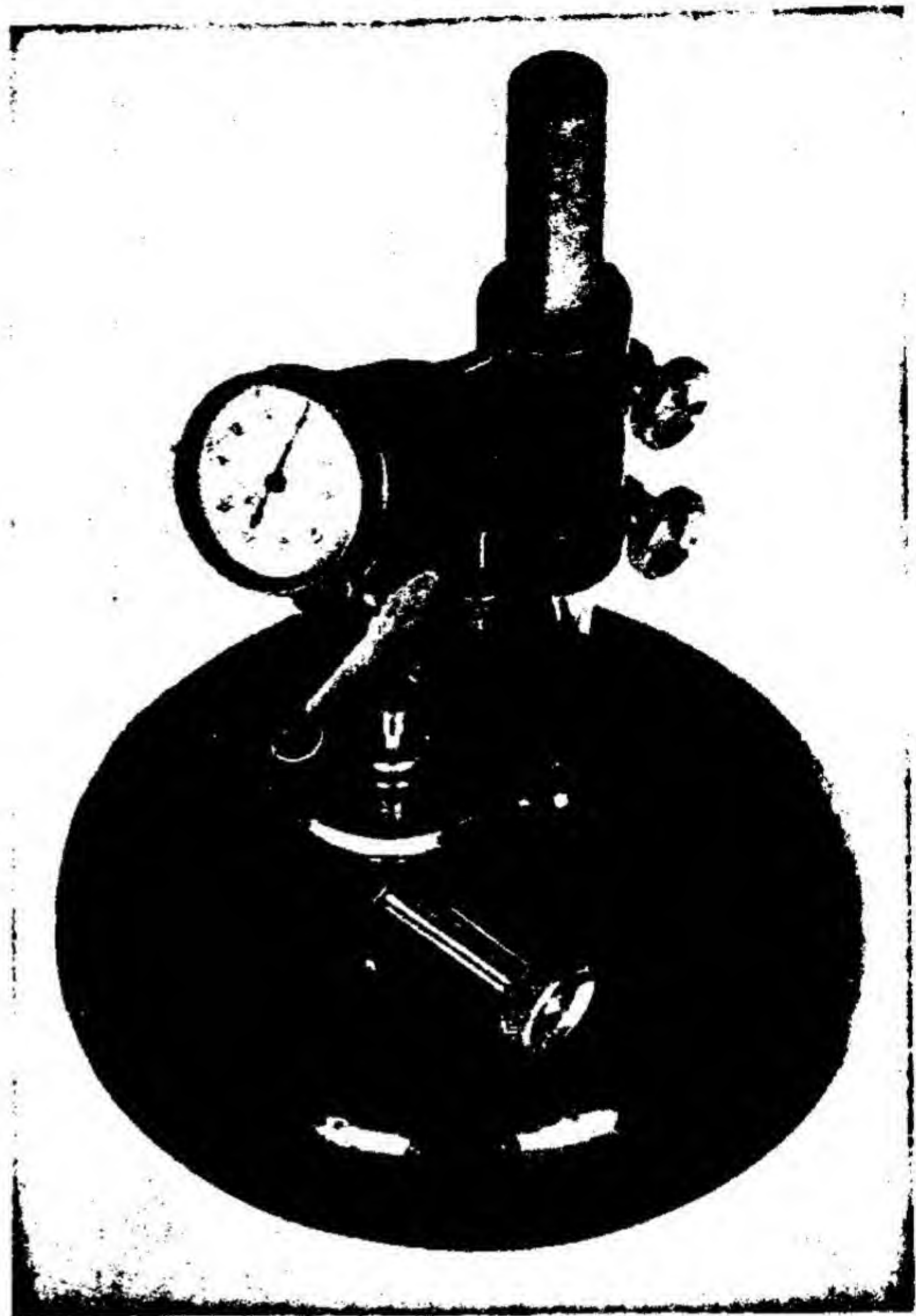


Fig. 33. Paper gauge.

### Thermometers

In addition to the usual thermometers necessary for a chemical laboratory, a set of thermometers should be available for field work. These thermometers should cover a range from  $-30^{\circ}\text{F}$  to  $300^{\circ}\text{F}$ . One important use of these will occur in motor vehicle homicides when a suspected car is discovered in a garage a short time after the occurrence. A temperature reading of the water in



the radiator should be taken immediately. The car motor should then be run until the water is fully heated, and the temperature should be read once more. A series of readings should be taken as the water cools to the temperature of the first reading. The time at which each reading is taken should be recorded. In this way it is possible to verify in part any excuse or alibi which the driver of a car may offer.

### Balances

**Analytical Balance (Fig. 35)** — A standard type analytical balance is needed for quantitative analyses. It may be equipped with a graduated beam and rider



Fig. 35. Analytical balance.

or with a chainomatic device. Such a balance will ordinarily weigh up to 200 grams and be sensitive to 0.1 mg. The investigator should be aware of the limits of accuracy of the balance which he is using. Normally an accuracy of 0.1 per cent is expected in weighing an 0.1 gram sample.

**Coarse Balance** — For weighings which do not require great accuracy (such as weighing large quantities of photographic materials) a rough balance should be employed. A set of rough weights should be used with this balance.

**Platform Balance** — For gross weighings a large balance is needed. A capacity of 100 lb is satisfactory.

### Measuring Tape

For measuring relatively great lengths such as the lengths of skidmarks or room dimensions a 50-ft steel measuring tape should be available. See Chapter 25 for the use of the steel tape.

### Spring Joint Rule

This should be available for measuring short distances such as the length of a person's step or the width of a window. In photography at the scene of the crime a rule should be included in the photograph as an internal standard of length. A spring-joint rule is satisfactory for this purpose because the extended section of the rule can be made to stand on the unfolded part (unless the rule is fully extended). In this position the rule can be conveniently placed against the object which is to be photographed.

### Stop Watch

The question of time frequently becomes significant in judging the reliability of a suspect's story. In homicide, the gravity of the crime increases greatly when



it can be shown that the element of premeditation was present. For example, if the defendant states that he struck the deceased in the heat of passion, and if it can be shown that in order to deliver the fatal blow it was necessary for him to walk through several rooms; then measurements of probable time consumed in traveling that distance become important.

Similarly, it may be necessary to measure the time required for a vessel such as a bathtub to be filled with water; for an automobile radiator to cool to a certain temperature; for a car to pass certain traffic lights. Although an ordinary watch will usually suffice for these measurements, it is well to have available a good stop watch in the event that a necessity for critical measurements arises.

### Cathetometer

This is another instrument for the measurement of length. The cathetometer or height gauge is specifically designed to measure height. A metal block slides on a vertical pillar. A telescope equipped with cross hairs is mounted horizontally on the metal block. The relative height of the telescope is indicated by the vernier on the block which moves along a scale on the pillar. The instrument is excellently adapted to measuring capillary rise, stretch of wires, the distance between two points of a cord suspended under a fixed tension, etc.



Fig. 36. Analyzer for electrical testing.



(a)



(b)



(c)

Fig. 37. Fuses "blown" from different causes: (a) In good condition, window clear (b) blown by short circuit; (c) blown by overload.



## Electrical Measuring Instruments

Accidents and crimes involving damage caused by electricity sometimes require an investigation to determine cause, negligence, or intent. Various parts of the electric circuit must be tested. For this purpose a voltmeter, ammeter, and ohmmeter are necessary. An electric circuit analyzer such as that shown in Fig. 36 is an excellent combination of a number of these instruments. Tested materials should also be at hand for comparison. Fig. 37 shows a set of fuses, each of which has blown from a different cause.

## EXERCISES

Before each reading with any measuring instrument a zero reading is always taken to see if the zero on the vernier coincides with the zero on the main scale. If this is not the case, a zero correction is necessary. It can readily be determined whether this quantity should be added to or subtracted from the actual reading. Each reading should be taken at different points of the specimen.

1. If possible obtain two pairs of dice, one a normal pair and the other a pair which has been altered by changing the slope or a dimension. Select a die from each of these pairs. Using the vernier caliper on each die take nine measurements of the thickness along each dimension. Calculate the arithmetic mean, the standard deviation, and the probable error for each dimension.

2. Using the micrometer caliper take nine measurements of the diameter of a cartridge shell. Calculate the arithmetic mean, the standard deviation, and the probable error.

3. Using a spherometer, determine the number of revolutions of the disk required for traversing one division on the vertical scale. Place the spherometer on a plane surface — a glass plate — and turn the screw down slowly, taking care to equalize the pressure, until the point of the screw just touches the plate. To determine if contact has been made, tap a leg of the spherometer gently to see if the instrument revolves. Note the reading on the two scales, taking care to read in the correct direction. Repeat this procedure nine times using a different part of the plate each time, and determine the zero reading of the spherometer.

4. Place the instrument on the convex lens surface and take nine readings. To determine  $h$  bring the screw-point into the same plane as the three leg-points and measure the distances from the point of the screw to the ends of the three legs by placing the instrument on a steel scale. Read to hundredths of a centimeter. Take three readings for each leg. Compute the arithmetic mean, standard deviation, and probable error for each set of readings and determine  $R$ .

5. Using the Geneva gauge take a series of measurements on the rims of four or five automobile lenses. Consult lens catalogues for the diameter of each lens. Measure the diameter of each lens with a large vernier caliper. Compare the three values obtained by these methods for each lens. Note that frequently the lens rim is too roughly made to justify the use of the Geneva gauge.

6. Using a metal cylinder of large diameter, make a series of ten measurements of the curvature with the Geneva gauge. Check by means of the vernier caliper. Calculate the arithmetic mean, standard deviation and probable error.

7. With the micrometer microscope make nine independent readings of two adjacent divisions of a stage micrometer scale. Determine the *calibration constant* of the instrument,



i.e., the number of centimeters per torsion head division. Compute the arithmetic mean, standard deviation, and probable error.

8. Select a set of scratches made by a screw driver and measure the distance between two chosen lines using the micrometer microscope. Measure the corresponding marks on the screw driver and compare the results.

9. Type a series of four capital and minuscule "a's" on a sheet of paper, using a different typewriter (of the same model) for each pair. Measure the height of each letter and compare the results. Determine any statistically reliable differences.



# CHAPTER 7

## DENSITY DETERMINATIONS

### 1. APPLICATIONS

In the identification of substances for scientific forensic purposes, physical properties assume a position of great importance because of the peculiar nature of the problem which the police laboratory faces. First, the sample received in the laboratory may be so limited in quantity that chemical analysis (except by spectrography or x-ray diffraction) is frequently prohibited. Second, methods of analysis which preserve as far as possible the original form and quantity of a small sample are preferable. Third, the preservation of the sample permits the checking of the results of the experiments.

Specific gravity or density is an especially important physical property from the viewpoint of the criminalistician. The most obvious example of its importance is offered by glass. In a relatively large number of laboratory cases, samples of glass are submitted for comparison. The reason for this can be understood from the fact that burglaries and assaults involve the breaking of glass. The fragments found on the suspect's clothing are frequently so small that the size and quantity available precludes chemical analysis, except spectrographically. In small laboratories, however, this elaborate equipment may not be available, so that the police scientist frequently must rely upon comparisons based on physical properties, density and refractive index among others.

The determination of specific gravity is useful also as a means of identification of pure liquids. In mixtures of known liquids such as alcohol and water, specific gravity is a rapid means of quantitative analysis.

### 2. DEFINITIONS

The nature of density is expressed by the equation

$$d^t = \frac{m}{v} \text{ g per cc} \quad (1)$$

where  $d^t$  is the absolute density at temperature  $t$ ;  $m$ , the mass; and  $v$ , the volume. In cgs units density can be expressed in grams mass per cubic centimeter. The



milliliter, however, is the more common unit of volume, particularly where liquids are being measured. The milliliter is defined as the volume occupied by  $10^{-3}$  kilogram of pure water at 3.98 C. The cubic centimeter is equivalent to 0.999973 milliliter. The *relative density* is defined as

$$d_4^t = \frac{m}{v} \text{ g per ml} \quad (2)$$

where  $t$  is the centigrade temperature at which the density is measured. The subscript "4" refers to 4 C, the density being measured relative to water at 4 C.

The specific gravity,  $d_t^t$  of a substance is defined as the mass  $m$  of a substance at  $t$  C relative to the mass  $m_0$  of an equal volume of water at  $t$  C:

$$d_t^t = \frac{m}{v} / m_0/v = \frac{m}{m_0} \quad (3)$$

The following relations exist between these three quantities:

$$d^t = 0.999973 d_4^t \quad (4)$$

$$d_4^t = d_t^t \cdot d_{4(\text{H}_2\text{O})}^t \quad (5)$$

and

$$d^t = d_t^t \cdot d_{4(\text{H}_2\text{O})}^t \quad (6)$$

### 3. EFFECT OF TEMPERATURE<sup>1, 2</sup>

Since the volume of most substances increases when they are heated to a higher temperature, the density will be found to decrease with temperature. For accuracy of  $\pm 0.001$  in measuring density, the temperature must be controlled within about one degree centigrade. The change in density with temperature can be calculated approximately by means of the coefficient of volume expansion,  $\beta$ , which is defined by the equation  $\beta = 1/v \cdot dv/dt$ . Values of  $\beta$  for various substances can be found in the usual tables of physical constants.  $\beta$  is of the order of  $10^{-4}$  per degree; it is not constant but increases with temperature (for liquids about one per cent per degree centigrade).

Differentiating equation (1) with respect to temperature (where density is represented by  $\rho$ )

$$\frac{d\rho}{dt} = -\frac{m}{v^2} \cdot \frac{dv}{dt} = -\rho\beta.$$

From this we have

$$\frac{\Delta\rho}{\rho} \cdot \frac{1}{dt} = -\beta.$$

In other words  $-\beta$  can be used as a measure of the relative change in density per degree centigrade.

### 4. DENSITY OF LIQUIDS

#### The Pycnometer<sup>3, 4, 5</sup>

The specific gravity bottle, or pycnometer, is the most common (and most accurate) device for measuring the density of liquids. Its usual design is that of a small flask with a ground glass stopper bored with a fine capillary. The sizes



should run from 1 to 30 ml. The accuracy of the measurement is not increased by using larger sizes than 30 ml. The pycnometer provides a known volume of a liquid in a form in which it can be conveniently weighed. Since the chemist is more interested in specific gravity than in density, he usually compares the weight of a volume of the liquid in question with the weight of the same volume of water at a specified temperature.

The pycnometer is first cleaned with cleaning solution and washed several times with distilled water. It is drained thoroughly and placed in a vacuum desiccator in an inverted position. After applying suction for 20 minutes or so, the pycnometer will be dried. This process is repeated until constant weight is obtained. The bottle is now filled with distilled water at a definite temperature such as 23 C or 25 C. Unless the pycnometer is equipped with a thermometer, it is necessary to immerse it for 20 minutes in a water bath at the stated temperature with the neck just above the surface. The stopper is now inserted with a twisting motion to avoid air bubbles. Since the bottle was full when the stopper was inserted, the liquid will rise in the capillary and overflow. These drops are carefully removed. The bottle is dried with a lintless cloth and weighed. The weight of water is then calculated. The procedure is repeated at other temperatures at which the bottle may be used such as 4, 10, 15.6, 20, and 30 degrees centigrade. The weights of water thus determined can be plotted against temperature. A straight-line graph should be obtained. This will serve as a check on the accuracy of the calibration and also as a means of calibrating the pycnometer for other temperatures. Excessive handling of the bottle should be avoided because of the danger of losing water through the capillary by expansion. The capillary should always be filled to the brim.

To determine the specific gravity of another liquid, the bottle is washed, dried, and weighed. It is then filled with the liquid and is again weighed. The weight of the liquid is calculated. The latter value is divided by the weight of water at the same temperature (equation 3).

The chief sources of error in the use of the pycnometer are the absorption of an uncertain amount of moisture by the glass and failure to insert the stopper to exactly the same depth each time. Third place accuracy is readily obtainable with the exercise of normal care. For fourth and fifth place accuracy, however, a number of further precautions are necessary. The technique of precision pycnometric measurements is described by Bauer. A precision of  $\pm 5 \times 10^{-6}$  gram per milliliter is possible under certain conditions.

### **Mohr-Westphal Balance**<sup>6, 7, 8</sup>

The specific gravity of a liquid can be defined as the ratio of the weight of a volume of the liquid to the weight of an equal volume of water (equation 3). From Archimedes' principle it can be seen that this ratio is equal to the ratio of the loss of weight of a body (a sinker) in the liquid to the loss of weight of the body in water.

This buoyancy principle provides the basis of the Mohr-Westphal balance, which is a rapid and accurate means of determining the specific gravity of non-



volatile solutions and nonhygroscopic liquids. The balance (Fig. 38) consists of a pivoted beam with one arm divided into ten equal parts, the tenth division being a hook at the end from which a sinker is suspended by means of a platinum wire. The ratio of the loss of weight of the sinker in water to the loss of weight in another liquid is, as explained before, the ratio of the densities of the liquids (an equal volume of the liquid being displaced in each case). The loss of weight of the sinker is calculated by first balancing the beam with the sinker in air and then noting the added weight required to balance the beam, when the sinker is submerged in the liquid. If  $L_w$  and  $L_x$  are the losses of weight of the sinker in

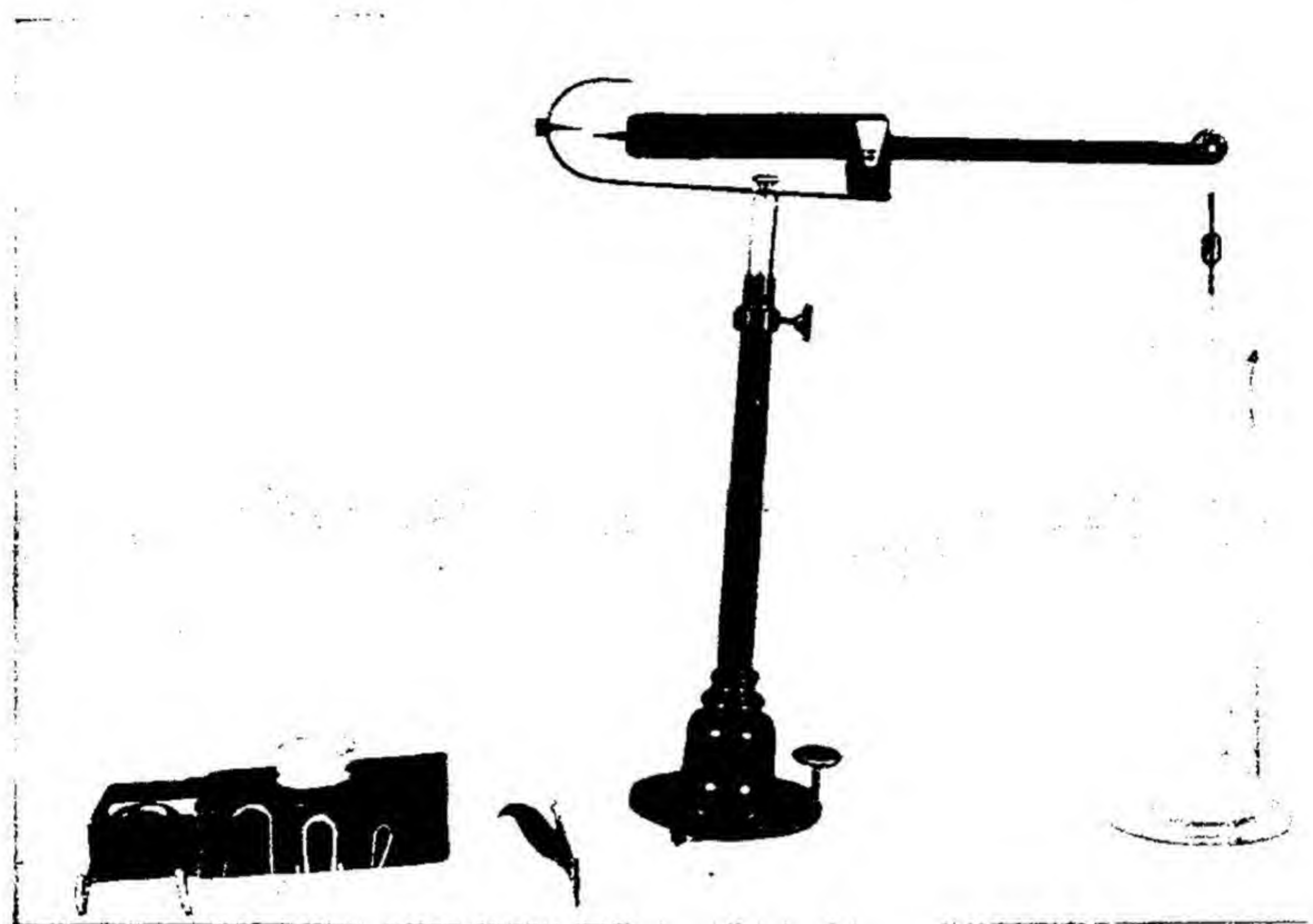


Fig. 38. Mohr-Westphal balance.

water and in the sample liquid, and  $d_w$  and  $d_x$  are the respective densities of the liquids,  $d_x$  may be found from the equation

$$d_x = \frac{L_x}{L_w} d_w$$

(This is another form of equation 6.)

The specific gravity is, of course, simply  $L_x/L_w$ .

Two sets of four different riders are provided with the balance. The relative values of the weights of the riders are 1, 0.1, 0.01, and 0.001. The numerical value of each rider in a weighing depends on its position on the beam with respect to the pivot. When the largest rider is on the hook — the tenth division — its value is 1.0; at the next division its value is 0.9; at the next 0.8; and so on. The next largest rider has a value 0.1 on the hook, 0.09 on the end notch, 0.08 on the next division, and so on. It is evident that the other two riders will have respective values 0.01 and 0.001 on the hook. If the 0.1 rider is at 9, and 0.01 at 3, and the 0.001 at 7, the reading is 0.0937. Another method of reading the Westphal balance is to immerse the sinker in distilled water with the unit weight in position. The threaded counterpoise is then turned until the pointers are



opposite each other. When determinations are now made with other liquids, they can be taken directly from the balance. A chainomatic type of Westphal balance is also available (Fig. 39). With this balance rapid determinations can be made with a precision of  $\pm 10^{-4}$ .

### 5. DENSITY OF SOLIDS<sup>9</sup>

The methods of measuring the density of solids depend on the immersion of the solid in a liquid of known density. They are less accurate than the methods for liquids because of errors due to inhomogeneities such as cracks or trapped air. Displacement methods<sup>10</sup> employing the pycnometer and the volumenometer are used as are also buoyancy methods. The latter techniques are found to be more useful in criminalistics. The free flotation method, in particular, is excellently adapted to comparison of the densities of small glass fragments.

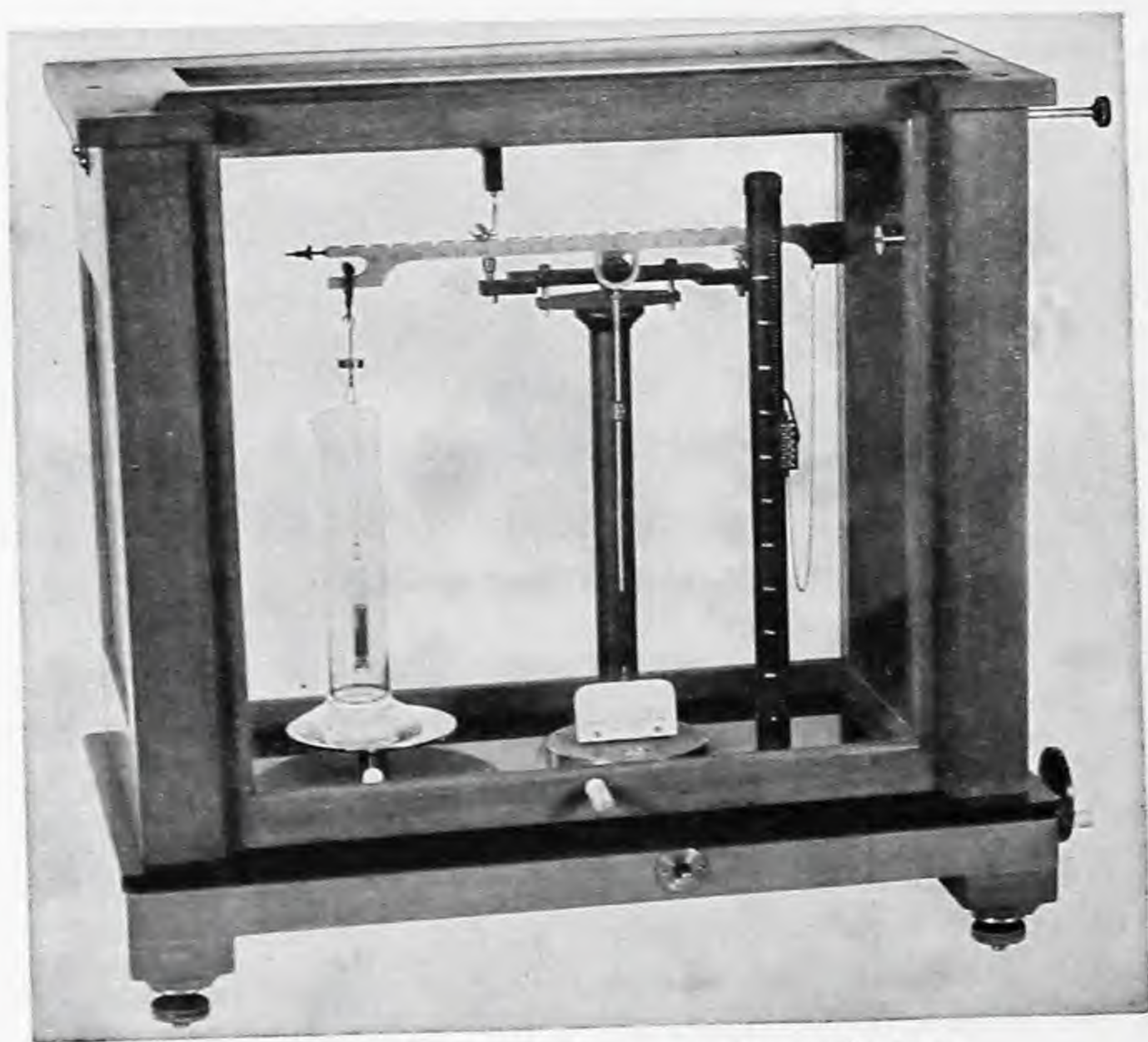


Fig. 39. Westphal balance, chainomatic type.

#### Free Flotation Method

A solid immersed in a liquid of the same density will neither rise nor sink. If the solid is immersed in a liquid of lighter density, a liquid of heavier density can be added until floating equilibrium is achieved. The density of the solid is then equal to the density of the liquid, which can be determined by any of the methods previously described. For the heavier liquid, methylene iodide or bromoform can be used; for the lighter, benzene or xylene is satisfactory. The



lighter liquid is gradually added to the heavier. In the critical region the addition of a few drops is sufficient to sink or float the specimen. The mixture should be carefully stirred with each addition. Care should be taken to remove air bubbles from the solid specimen. The accuracy of the determination by this method is, of course, limited by the accuracy with which the density of the liquid is determined.

One of the disadvantages of the method is the necessity of waiting until the two liquid components are thoroughly mixed and come to equilibrium with the solid. By using a centrifuge the process can be considerably shortened. A small sample of the solid is added to the liquid mixture and placed in a centrifuge, which is operated at 2000 to 4000 rpm for several minutes. The lighter or heavier liquid is added, depending on whether the solid sinks or rises. This procedure is repeated until the suspended solid remains relatively stationary. With 0.05 mg of a hydrocarbon ( $C_{21}H_{10}$ ) Bernal and Crowfoot<sup>11</sup> determined its density by this method with an accuracy of  $\pm 0.002$ .

A precision technique for detecting small density differences by the flotation method is described by Hutchison and Johnson.<sup>12</sup> When the immersion liquid and the solid have approximately the same density, the temperature of the liquid is changed a small amount. With a temperature control of  $\pm 0.001$  C, density differences of the order of  $10^{-6}$  were detected.

Roche and Kirk<sup>13</sup> describe a technique which permits a rapid and convenient determination of the specific gravity of small glass fragments. This is a flotation method employing a column of liquid in which the density varies with the height. Two miscible liquids of different densities (methylene iodide and nitrobenzene) are stratified in a long glass tube. The liquids are mixed only partially by gentle stirring with a glass rod, so that on standing a short time the resulting mixture possesses a fairly uniform density gradient. The glass fragments to be examined or compared are immersed in the liquid. After about fifteen minutes they come to rest at a position where the density of the liquid is equal to that of the glass. Further examination (such as refractive index or density by the centrifuge method) is necessary only for those glass fragments which float at the same level. A tube suitable for these tests is made from glass tubing (8 mm inside diameter) cut into 30 cm lengths. One end of the tube is sealed in the flame of a Bunsen burner.

### EXERCISES

1. Select three or four liquids such as bromoform, ethyl alcohol, and aqueous solutions of copper sulfate of known concentrations. Determine the specific gravity of each. Compare the results with the values given in any standard tables.
2. Select a set of ten samples of glass from different sources. Determine the density of each sample. Study the differences in values from the point of view of identifying each sample.

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# PART C

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## IMPRESSIONS

In this part a study will be made of the various traces which may be left by a criminal in the form of a finger-, palm-, or footprint or by means of a tool or piece of wearing apparel. To these traces we shall assign the general term *impressions*.

The importance of an impression as evidence lies in its uniqueness. A given impression can be produced by only one object. For example, a certain fingerprint can be produced by only one finger; a shoe print will correspond to only one shoe; a jimmy mark will bear the unique characteristics of the jimmy. Naturally, this uniqueness is invaluable as evidence; it can be established, however, only if there are a sufficient number of characteristic marks discernible.

There is a tendency among laymen (and law enforcement officials, too), to stand somewhat in awe of this fact of unique correspondence between fingerprint and finger. For them there is a sacredness and value (apart from classification systems) in a fingerprint which they will not grant to the palm print or the tool mark. The scientific criminal investigator, however, views the matter from a precisely contrary point of view: the unique correspondence between effect and cause, print and finger, tool mark and tool, is normally to be expected. Nature or artifice can only by the most improbable chance produce two objects which are identical in construction. All material objects may be looked upon ultimately as configurations of molecules much as a house is an assembly of bricks. The chance of all the bricks in each of two houses being placed in identically corresponding positions is too remote for consideration. Similarly, we must always expect differences, either macroscopic or microscopic, in any two objects, however alike may be the processes by which they are made.

The impressions produced by any two objects — two fingers or two jimmies — will differ under an examination sufficiently critical; hence unique correspondence is almost a law of nature and not an anomalous phenomenon, and our failure to perceive it is due to limitations in our methods of examination.

It is the task of the criminalistician to establish this correspondence between impression and object by discovering a sufficient number of characteristics in both to establish the relation. The impression is to be looked upon as a negative — a reversed image. The cast, mold, or other reproduction is a positive which will resemble in character the original object.



A preliminary step in the investigation of all impressions is the photograph. Two purposes are served by this measure: first, a record of the original state of the evidence is preserved for legal purposes; second, a likeness of the impression is obtained, so that if the impression is destroyed in the process of casting, molding, lifting, etc., the loss is not total. In connection with this latter purpose it may also be said that not infrequently the photograph will be a better reproduction than the cast or lift. This precaution of preliminary photography is so important that it will be repeated frequently at the risk of tedium. It is to be understood that in photographing impressions a ruler or scale must be included in the field.



# CHAPTER 8

## FINGERPRINTS

### DEVELOPING FINGERPRINTS BY POWDERING

#### 1. THE LATENT FINGERPRINT

The perpetual hope of the scientific criminal investigator at the scene of a crime is the discovery of a fingerprint which will point directly to the criminal. The fingerprint occupies a position of paramount importance in circumstantial evidence. There are many reasons for this: the simplicity with which fingerprints may be obtained; their conclusiveness in establishing identity; the immutable character of the fingerprint during life; and the existence of common filing systems.

A fingerprint is usually formed by friction ridges leaving a deposit of perspiration on the surface with which the finger has been brought into contact. Friction ridges are marked by fairly regularly placed depressions which are the sweat pores. Perspiration exuding from these pores flows over the ridges.

The untouched fingerprint on a surface is called a *latent fingerprint* because it is ordinarily not clearly visible. To render the print visible a powder is usually applied by means of a fine brush, a duster, or an atomizer. The powder adheres to the pattern of the finger made by the perspiration. The powdered print is usually photographed as a permanent record.

Before determining which powder to use in dusting a print, consideration should be given to the possibility of photographing the print without treating it in any manner. It sometimes happens that in powdering a print some of the detail is lost in critical areas. Frequently such a photograph is quite simple. In burglary cases, where the burglar's hands become dirty through his effort to gain entry, it is not uncommon to find visible prints on light colored walls or woodwork of the house. More difficult prints on glass or other surfaces may be made visible by oblique light which, exceeding the critical angle, will be reflected from the surface with sufficient contrast to its background to yield a satisfactory photograph (Fig. 40).



## 2. SELECTION OF POWDERS

The choice of powder is determined by several factors. First, the color of the powder should be selected to give in the photograph maximum contrast with the background. It is usually desirable to select a powder such that the



**Fig. 40. Greasy fingerprints on glass, photographed without powdering.**

result will be a black print on a light background. This is done for the convenience of the fingerprint experts, who are accustomed to examining a black print on a white surface. If it is necessary to use white powder on the surface, a transparency should be made later from the negative. These matters are discussed in detail in Chapter 16. Black powder, then, in general, is used on light backgrounds; a white powder is used on dark surfaces. Certain multicolor surfaces will present a problem: For example, if the print lies on a background of blue and white, it may be advisable to use a red powder to produce photographic contrast.

Another factor to be considered is the manner in which the powder adheres to the surface and to the print. Fingerprints vary in the amount of oily substance present in the perspiration deposited. The wrong choice of powder may lead to unfortunate results.

When we observe the delicate nature of a fingerprint under a microscope, the ease with which it can be altered or destroyed becomes evident. The qualities, however, of a suitable fingerprint powder are difficult to describe. The powder must, in the first place, adhere to the print. On the other hand, it should not cling too readily to the surface so that when the print is carefully brushed the powder while still adhering to the print, will not remain between the ridges.

The work of L. C. Nickolls<sup>1</sup> led to the following conclusions: (1) The utility of a fingerprint powder does not depend on its bulk density. (2) Amorphous powders are, on the whole, superior to crystalline powders. (3) Floury consistency is a desirable quality in a fingerprint powder.

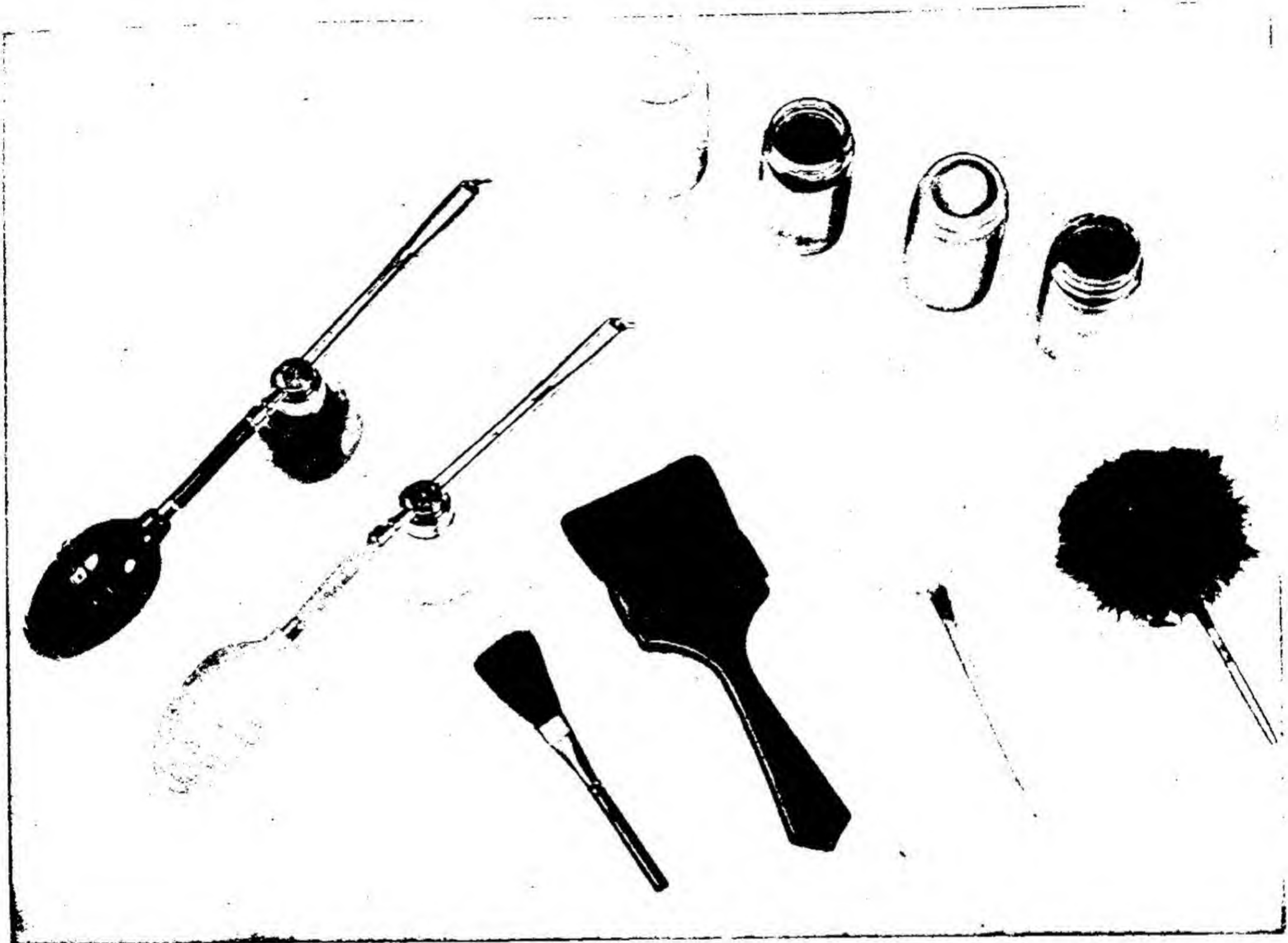
Few reliable recommendations can be made concerning the effectiveness of an individual powder in a particular case. In general the gray powders adhere better than the black ones so that, although glass is a light surface, it may be advisable to dust it with gray powder to bring out the details of the print. Knives and silverware should also be dusted with white powder because of this adhering quality.



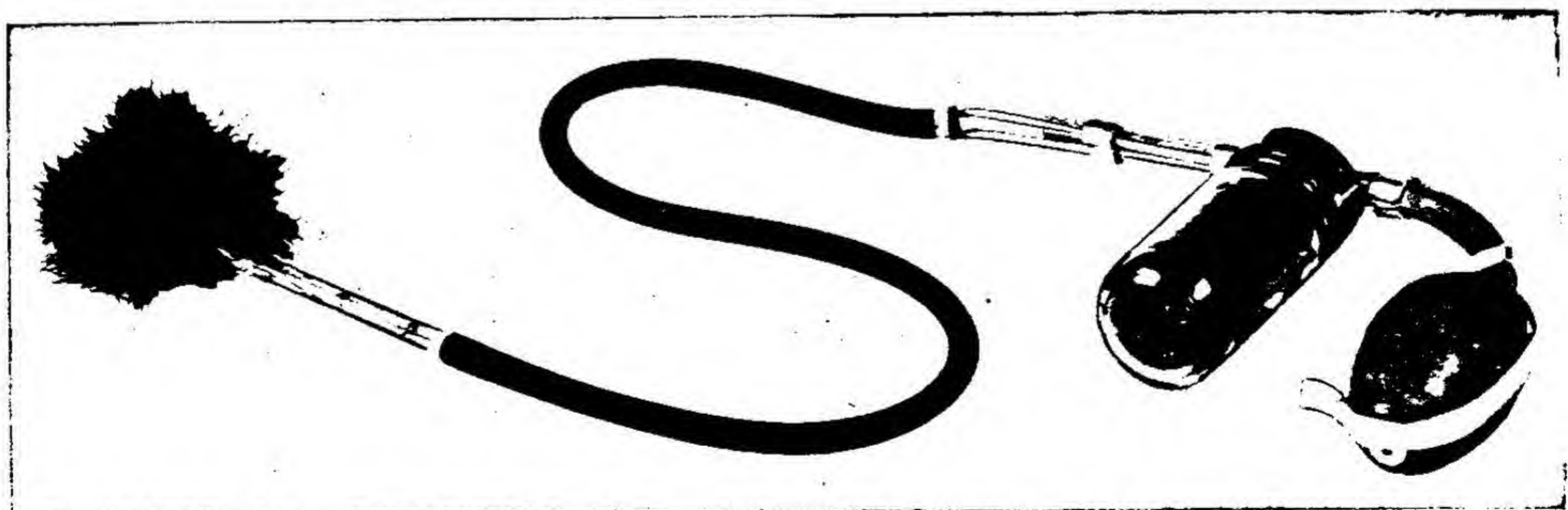
The following are some typical fingerprint powder formulas:<sup>2, 3</sup>

a) Lampblack	70 parts
Graphite	20 parts
Powdered acacia	10 parts
b) Mercury and chalk	75 parts
Talc	25 parts
c) Mercury and chalk	85 parts
Aluminum	15 parts

d) Aluminum	75 parts
Charcoal	20 parts
Dragon's blood	5 parts
e) Lampblack	60 parts
Resin	23 parts
Fuller's earth	17 parts



(a)



(b)

Fig. 41. (a) Powders, dusters, and blowers for developing latent fingerprints; (b) A modification of the equipment shown in (a). (Courtesy, Act. Sgt. Ralph Dudley, New York Police Department.)



In a case of a delicate print it is always advisable to try several powders. Before powdering any surface the technician should first determine whether it is possible to place a print on the surface. He should place his own print on an untouched area and should then experiment in powdering it.

### 3. POWDERING OR DUSTING

There are several methods of powdering or dusting a latent print. For large areas a camel hair brush of three or four inches width is sometimes used. The



**Fig. 42. Technique in powdering a print: (a) Correctly developed print; (b) detail obscured by an excess of powder; (c) streaks caused by excessive vigor in brushing.**

atomizer is also used for this purpose and is fairly satisfactory except for an unfortunate tendency to become clogged because of imperfections in the granulation of the powder. A brush must also be used in conjunction with the atomizer to remove excess powder. The best instruments for powdering are the ostrich feather duster and the round camel hair brush, one to two inches long.



**Fig. 43. Correct method of picking up powder on a duster.**

In applying powder with a brush or duster considerable care must be exercised. The most serious errors are the use of too much powder and too much force (Fig. 42). The powder should be shaken out of the bottle into a shallow, wide container (Fig. 43). The brush is dipped lightly into the receptacle and the excess powder removed by tapping the brush lightly. The brush is then drawn delicately across the surface until the latent print becomes visible. After the first ap-

pearance of the print the brush should be applied in the general direction of the ridges. When sufficient powder is adhering to the print, the



brush should be shaken free of material and then applied with great care to remove excess powder such as that lying between the ridges.

In summary, the following rules may be used as a guide:

1. On discovering a fingerprint, photograph it before processing.
2. Determine whether the surface under examination will "take" a print by attempting to place one on and then developing it.
3. In developing with a duster or brush always use a very light stroke and a small amount of powder. One careless stroke can destroy the value of a print.
4. Photograph a print as soon as it has been developed.



Fig. 44. Poor technique — the brush should not be pushed into the bottle.

## LATENT FINGERPRINTS BY OTHER METHODS

Frequently the substance which must be examined for latent fingerprints is of such a nature that the prints will not readily respond to the usual treatment by powders. Paper, wood, and cloth are examples of such materials. If a powder is used at all with objects of this nature great care must be exercised to avoid smudging. Several processes are employed for developing latent prints on such surfaces. The choice of method should depend upon the nature of the surface and the time which has elapsed since the prints were made.

### 4. RECENTLY MADE PRINTS ON PAPER<sup>4, 5</sup>

If it is known that a sheet of paper has been handled within the last two or three days and if it is desired to develop latent prints, certain powders may be used with success. The powder should be sprinkled over the paper and the paper then agitated so that the powder rolls over the proper areas. When a print is sufficiently developed, the paper is then tapped on the reverse side to remove unnecessary powder (Fig. 45). Brushing on the powder is also effective.

The powder chosen for this purpose should be selected for its adhesive qualities as well as for color. Graphite, lampblack, aluminum, metallic antimony, bronze, and similar fine-grain powders may be used. The choice of color will depend, as usual, on the background. Where a multicolor background is



encountered, a fluorescent powder such as fluorene or anthracene should be used and a photograph made in ultraviolet light.

## 5. REAGENTS ON PAPER, WOOD, AND CLOTH

The use of chemical reagents which will act on the compounds found in the perspiratory excretion constitutes a simple and effective means of developing latent prints. The print which is received by paper through handling is merely an outline of the friction ridges made by the perspiration which exudes over them from the sweat pores. Perspiration consists of 98 per cent water with traces of salts, such as potassium chloride and sodium chloride, sulfates, phosphates, carbonates, lactic acid, fatty acids, glucose, and urea. Chemical methods of

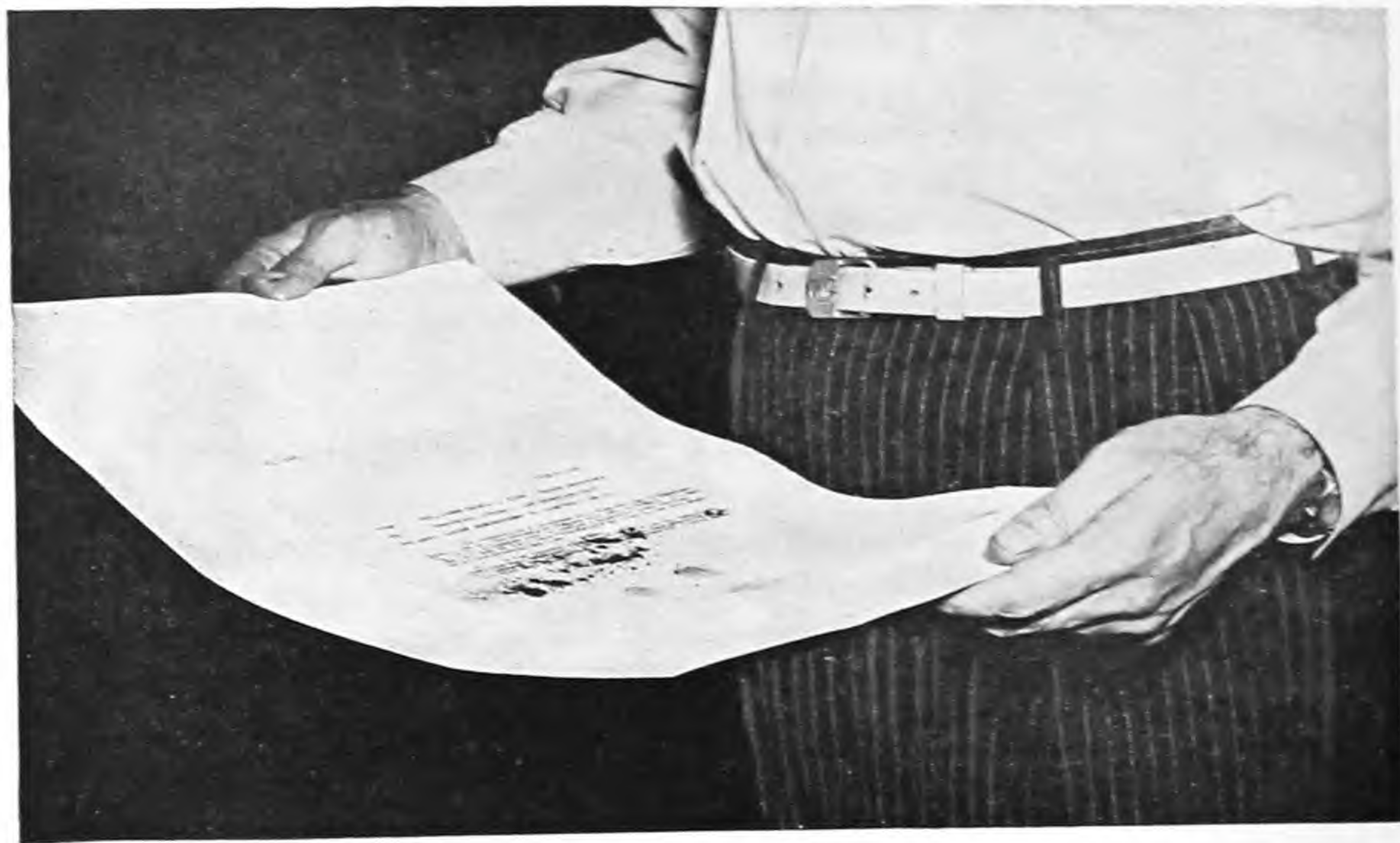


Fig. 45. Developing fresh prints on paper.

developing latent fingerprints ordinarily make use of the presence of the chlorides in the latent image by exposing the paper to the action of some chemical which will react with the chlorides to produce a visible print.

## 6. SILVER NITRATE<sup>6, 7, 8</sup>

If it is thought that a sheet of paper bears latent prints which are several weeks old, the silver nitrate treatment should be used. As a general all-purpose developer of latent prints, silver nitrate is very satisfactory. The papers are immersed in trays containing approximately a 5 per cent solution of silver nitrate. The silver replaces the sodium and potassium giving silver chloride;



viz.,  $\text{AgNO}_3 + \text{NaCl} \longrightarrow \text{AgCl} \downarrow + \text{NaNO}_3$ . The papers are then hung up to dry over a sink in a darkroom. After drying they are exposed to sunlight or to a powerful artificial light such as a carbon arc (Fig. 46). On exposure to light the silver chloride yields free silver which appears as a dark outline of the friction ridges:  $2 \text{AgCl} \xrightarrow{\text{light}} 2 \text{Ag} \downarrow + \text{Cl}_2$ . The print must then be photographed before the paper completely darkens.

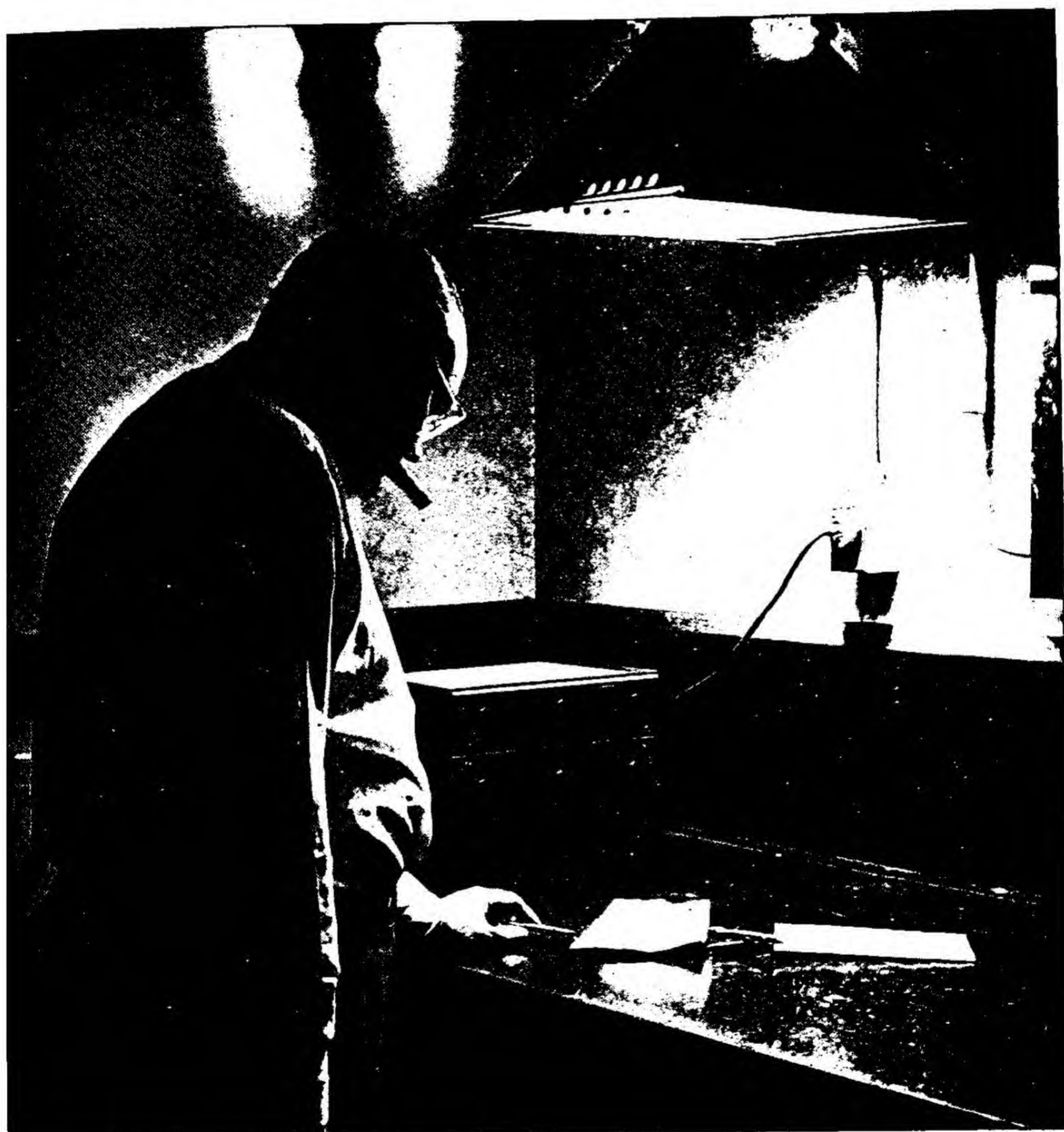


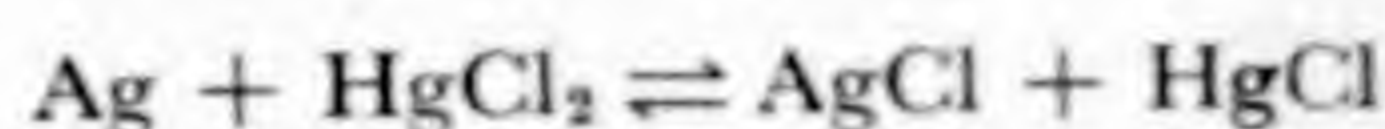
Fig. 46. Exposing paper to a carbon arc lamp after the silver nitrate bath for the development of latent prints.

After being photographed, the print can be preserved by placing it in a lightproof envelope, or by chemical fixing with hypo (sodium thiosulfate). It will be noted that this whole procedure is similar to the photographic process: the light deposits free silver, and the hypo removes the unaffected silver chloride.



Instead of exposing the paper to light, the latent image may be darkened chemically by washing first with distilled water and then dipping into a solution containing one part of 35 per cent formalin to ten parts of 2 per cent sodium hydroxide. This bath reduces the silver chloride to metallic silver.

Frequently it is requested of the laboratory that a paper be examined for prints and then restored to its original condition if no print is found. This can be accomplished by immersing the paper in a solution of mercuric chloride, after the examination by silver nitrate has been made, and then hanging up to dry. The reaction is:



Both reaction products are white and may be removed by rinsing in water.

Examinations for latent prints on letters are of common occurrence in cases of blackmail, forgery, anonymous and threatening letters, etc. The laboratory will find need of a permanent arrangement for the silver nitrate development procedure. A special sink may be set aside for this purpose. Wires should be suspended over the sink for holding clips by which the papers will be hung to dry. Several pairs of rubber gloves should be provided to protect the operator's hands from the silver nitrate solution. Talcum powder should be available to facilitate donning the gloves. Several shallow trays should be used for the baths.

## 7. OSMIUM TETROXIDE <sup>9</sup>

In liquid or vapor form osmium tetroxide may be used on paper to develop latent prints which are of fairly recent origin. Because of the highly poisonous nature of osmium tetroxide, it is usually preferable to use silver nitrate; however, in capable hands, osmium tetroxide can be made to yield excellent results. A small quantity of a 1 per cent solution is used. The vapor form will be found more effective than the liquid. A fuming chamber such as the one shown in Fig. 229 may be used. A small quantity of the solution is placed in the evaporating dish, and a Bunsen burner applied to the dish for a few seconds. The paper should be exposed to the fumes for an hour or more until no further development is observed. For convenience the paper may be exposed to the fumes overnight, since the prints so developed are not fugitive and need not be fixed. Of course, a photograph should be made of the prints as soon as possible.

The action of osmium tetroxide on a latent print depends upon the fatty substances which are found in the secretion of the glands. In the presence of these substances the osmium tetroxide is reduced to free osmium, which is dark in appearance as are most finely divided metals. The osmium tetroxide method reveals fine detail in recent prints, but it is not as effective as iodine on prints several months old.

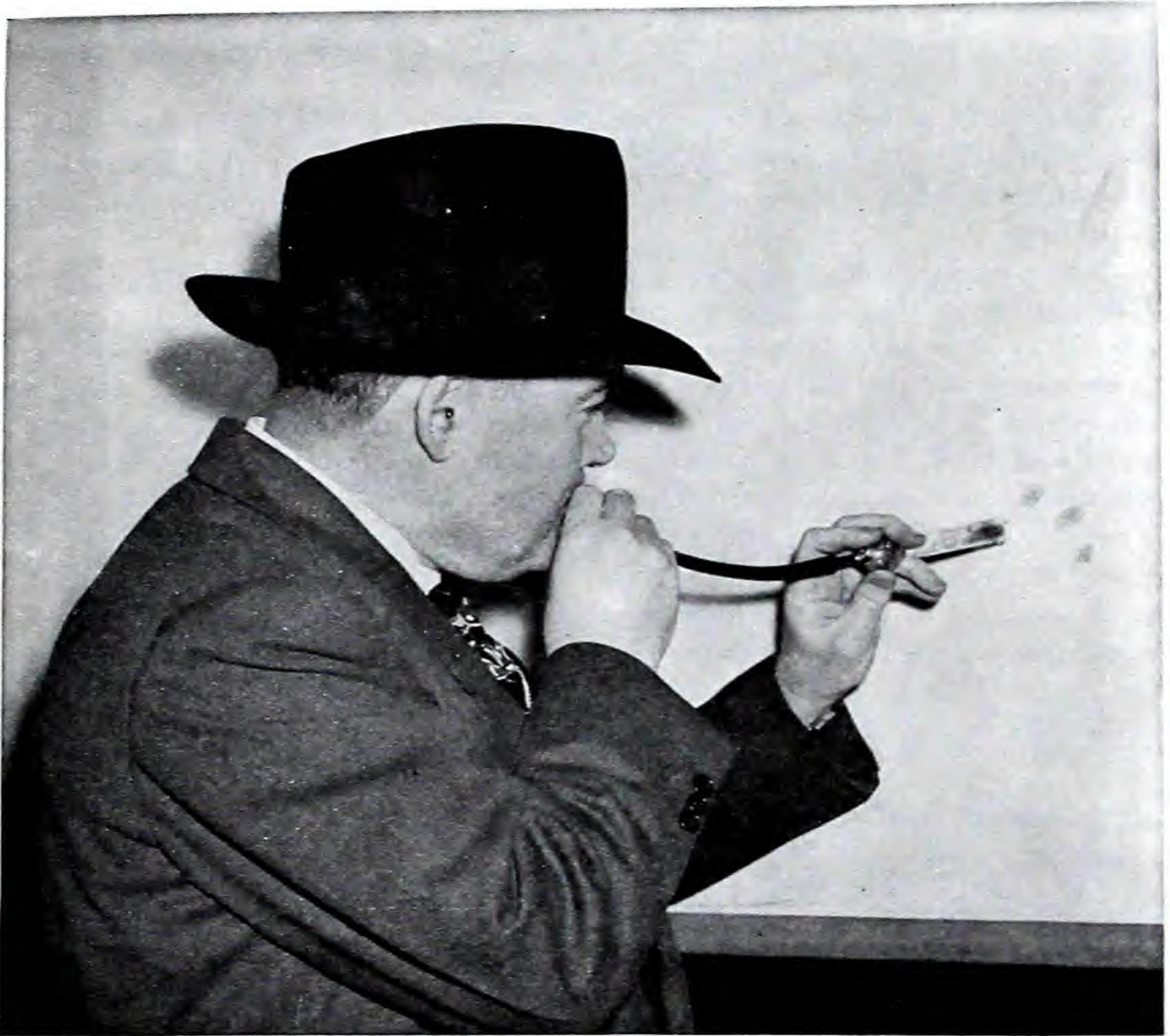
## 8. IODINE

Iodine fuming is another satisfactory developer for fingerprints on paper. The procedure is similar to that used with osmium tetroxide. Iodine crystals are placed in an evaporating dish in the glass chamber in the presence of the



paper to be treated. The dish is heated for a short time until the fumes are seen to rise. The latent print will darken as the vapor clings to the secretions.

Greater control over the process can be achieved by allowing the iodine to sublime at room temperature instead of applying heat to the dish. The time necessary to develop prints in this manner is, of course, much longer. When the room temperature is relatively low, it may be well to leave the paper in the presence of the crystals overnight. This is sometimes called *cold development*.



**Fig. 47. Developing fingerprints by iodine fuming.**

An iodine print is fugitive and, unless some precaution is taken, the print will soon disappear. Since it is always necessary to photograph the prints, it is well to place the paper in a photographic printing frame immediately after development.

Several methods of fixing iodine prints are recommended. A silver plate transfer method will be described later. Another method of preserving the print is the following, attributable to Wagenaar:<sup>10</sup> twenty grams of rice starch are



mixed with 20 milliliters of water to form a paste; 2 grams of potassium iodide and 0.3 grams of thymol (as a preservative) are then added and carefully mixed. This paste is spread on a sheet of paper. Before the paper becomes quite dry it is pressed against the iodine, and the print is now on the prepared paper. Several prints can be made in this manner. For greater permanency they can be later varnished with a 3 per cent solution of gum dammar in benzol. This print is a mirror image of the print as it is usually viewed.

Another simple way of preserving iodine prints is to place the paper containing them between two glass plates and sealing the plates with transparent tape or one of the sealing cements common to chemical laboratories. Other methods are given by Bridges<sup>11</sup> and Popp.<sup>12</sup>

To remove prints which have been developed by iodine fuming, the paper is simply treated with ammonia fumes. The removal of iodine may also be accomplished by exposing the paper to air for several days, thus permitting the iodine to sublime.

The use of iodine vapor is by no means limited to fingerprints on paper. This fuming method is effective also in the development of greasy fingerprints such as those found in kitchens or garages. Powdering in such cases would lead to smudges. An apparatus for rapid fuming with iodine is easily made in the laboratory. A straight calcium chloride tube (with one bulb) is packed with a small wad of glass wool at the bulb end. This is done in order to prevent solid particles of calcium chloride from passing through to the rubber tubing which is connected at this end of the tube. Sufficient calcium chloride is added to fill about three-quarters of the tube; another wad of glass wool is inserted and a small quantity of iodine crystals is placed on top of this; a third wad of glass wool is used to hold the iodine crystals in position. By blowing gently through the rubber tubing, a cloud of iodine is directed toward the surface being examined for fingerprints (Fig. 47).

## 9. ADDITIONAL METHODS

The field of fingerprint development has been quite fruitful of ingenious methods. A few of these are given below. Most of them are of academic interest only, since one will usually rely on the techniques already described.

*Heat* — Prints on paper can be sometimes developed by applying a hot iron to the surface. The charred organic material of the perspiratory excretion forms the outline of the print.

*Colored Solutions*<sup>13, 14</sup> — The preferential wetting of paper by a colored solution such as an ink will permit the print to stand out in contrast. Mitchell recommends the following solution: 2 ml osmic acid, 2 ml water, and 0.05 g pyrogalllic acid.

*Dyestuffs*<sup>15, 16</sup> — The print is powdered with a dye and fixed by exposure to the fumes of acetic acid and steam. Thomas recommends waxoline yellow O5, waxoline orange AX, waxoline red AS, and waxoline violet 2 BS.



*Hydrofluoric acid* — This is applied to fingerprints on glass. The area between the ridges is etched by the acid. The waxy substance of the print itself repels the liquid.

*Reducing agents* — An organic reducing agent of the photographic type such as amidol, pyrogallol, or hydroquinone is brushed on the print. A piece of photographic film is pressed against the print, developed in ammonia and water vapor, and fixed in hypo.

*Tannic acid* — A 10 per cent solution of tannic acid is used to set the albumin present in the print.

*Fleming's reagent* — Marks containing a fatty substance are treated first with Fleming's reagent (a mixture of osmic acid, chromic acid, and glacial acetic acid) and then with a liquid which fluoresces in ultraviolet light. The result is photographed under an ultraviolet lamp.

## FINGERPRINTS AT THE SCENE OF THE CRIME AND SPECIAL TECHNIQUES

### 10. HOUSES

The most common crimes to which the services of the laboratory are summoned are burglaries. On arriving at the scene the laboratory investigator should make a survey of the interior and exterior of the premises, obtaining the necessary information from the detective assigned to the case. It is usually possible to determine the point of entry and the approximate path of the criminal in the interior. This path should suggest the order in which the various areas should be processed.

The exterior of the premises does not usually yield any prints. The dust which covers the window ledges and doors prohibits good impressions. Clean windows are the most likely source of prints.

Before processing the interior a photograph (35 mm camera) should be made of each room which is being considered. The photographic record will be invaluable as an aid to remembering the location of various objects in the event of testifying in court.

### 11. VEHICLES

The examination of automobiles is another frequently occurring task in fingerprint work. If the car has been exposed to the rain, it should be permitted to dry thoroughly with open windows before being processed for prints. Similarly, if the car is found at night with a heavy deposit of dew, it is advisable to wait until the next day.

The most fruitful areas in the search for prints are the front door windows, window ledges, and areas near the door handles. The rear view mirror sometimes bears a thumbmark from the readjustment usually necessary for the driver of a strange vehicle. The steering wheel and dashboard seldom yield good prints.



## 12. VARIOUS SURFACES

The general methods described above will be found adequate to deal with the great majority of fingerprint cases; many special cases, however, will be met in the course of time. Fingerprints on raw wood, leather, cloth, etc., present individual problems. A number of these surfaces are discussed below and recommendations for their development, which have been made by various authorities, are given. Again the precaution of photographing before developing must be repeated. Careful oblique lighting of many of these surfaces will reveal the print impression satisfactorily so that it may be photographed.

### Polished Wood

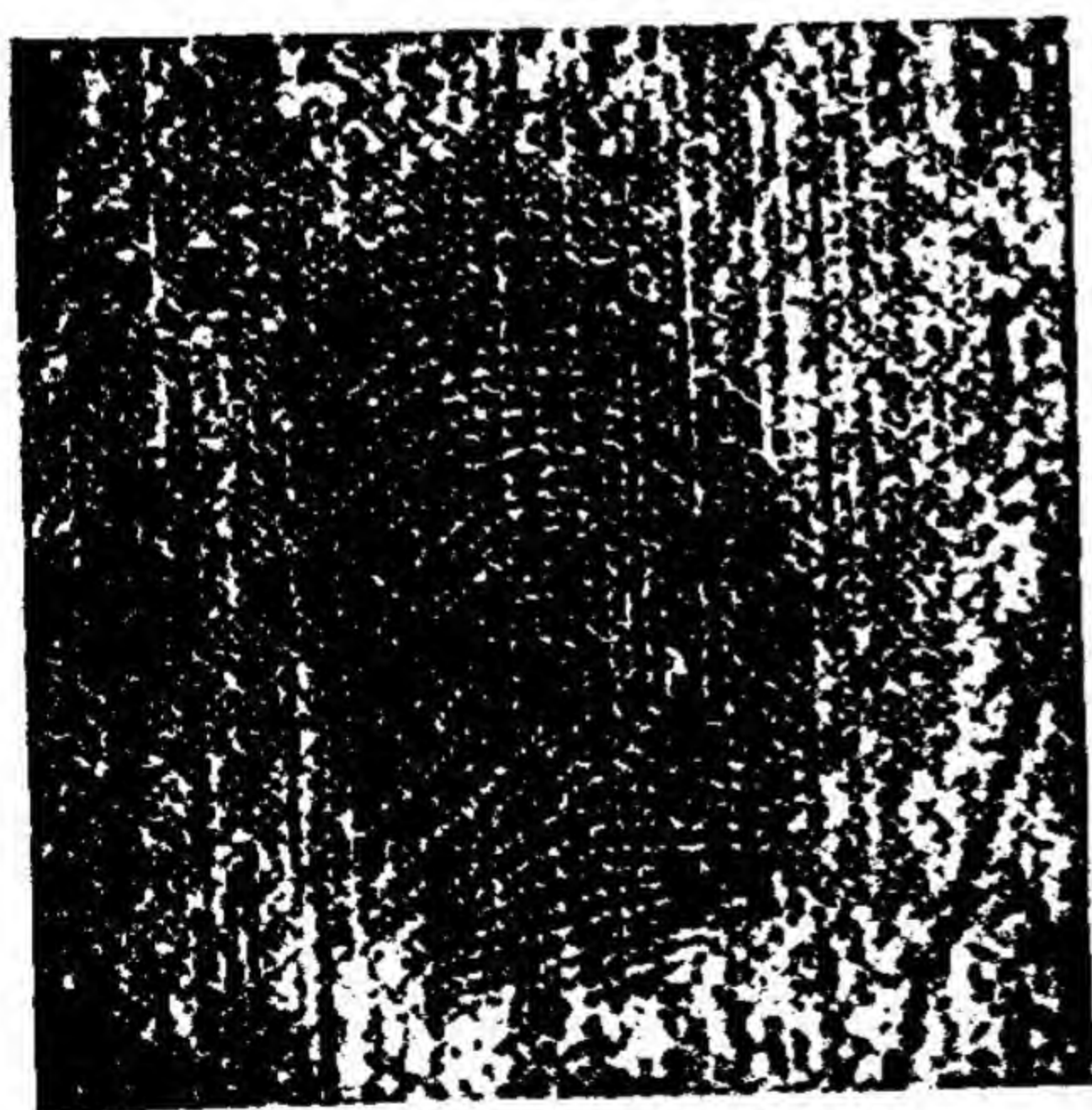
Spray on a powder using an atomizer. Brushes and dusters are also adequate if it is found that the surface is not greasy and does not smear readily. If the wood is of light color iodine fuming is effective.

### Greasy Surfaces

On kitchen windows and walls there may be a thin film of grease. Mercury with chalk powder gives good results. For excessive grease iodine fuming is recommended. The portable iodine fuming apparatus is excellent for this purpose.

### Raw Wood

Silver nitrate should be used on raw wood surfaces. If the surface is part of the handle of an instrument or if it is conveniently portable, it should be removed to the laboratory for processing. For doors, walls, or roofs a liquid sprayer or glass fiber brush may be used and the prints photographed at the scene. If the surface is even, a roller may be used. The roller is immersed in the solution and run back and forth over the surface. Successful development of prints on raw wood surfaces is quite rare.



**Fig. 48.** Latent fingerprint on cloth developed by the silver nitrate process.

### Cloth

Coarse fabrics such as towels do not possess the proper continuity of texture for a good print. Sheets, pillow slips, handkerchiefs, shirts, and other fine fabrics, especially if they are sized or starched, will respond to the silver nitrate method (Fig. 48). The garment is immersed in the solution and treated in the usual manner. If no fingerprints are found and it is desired to restore the garment to a usable condition, it should be rinsed thoroughly in water and then immersed in a very dilute solution of ammonium hydrosulfide. The cloth will first turn dark and then become light. It should again be rinsed thoroughly and hung to



dry in the sunlight. Iodine fuming also is recommended for developing prints on cloth. Prints are very seldom found by either method.

### **Black Satin**

Smooth the material on a frame and develop with calcium sulfide powder. Remove excess powder by tapping the frame. To retain the print after photographing, the cloth must be left on the frame. The probability of finding a print is extremely small.

### **Raw Leather**

The silver nitrate method as used for cloth; low probability.

### **Finished Leather**

The choice of powder will depend primarily on the color of the leather. Copper powder has been found to give good results. Aluminum powder is also satisfactory.

### **Fingernails and Toenails**

Copper powder will develop prints on these surfaces.

### **Fruit**

Apples, oranges, bananas, etc., will retain a fingerprint. Lead carbonate is excellent here.



Fig. 50. A "plastic" print on adhesive tape.



Fig. 49. Latent fingerprint developed on cigarette paper.

### **Cigarette Paper**

Slit the paper to remove tobacco and develop with iodine fumes. Silver nitrate will also give good results (Fig. 49).

### **Prints or Impressions on Plastic Substances**

Substances such as soap, fat, butter, tar, paraffin, or adhesive tape (Fig. 50) receive an impression when a finger is placed on them. This impression should be photographed with the proper lighting. A plaster cast of the print can then be made from the substance. Wood's metal is also suited to this work where the



surface does not have a low melting point. A small amount of Wood's metal is heated to about 70 C (the melting point) and poured carefully on the print.

### **Bottles**

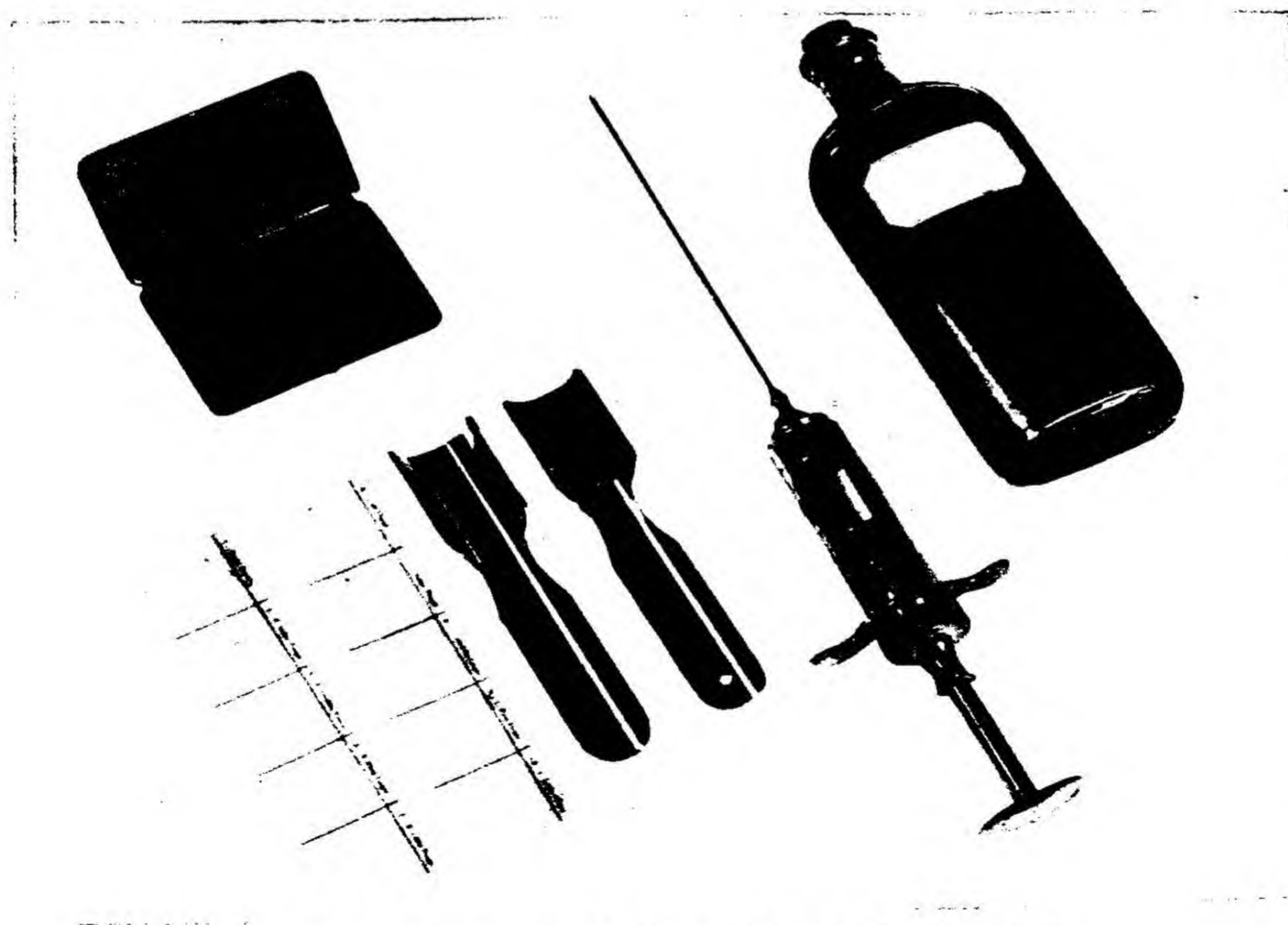
If a print is found on a bottle of light-colored glass, an aluminum or white powder is used. A dark fluid such as ink is poured into the bottle to give a contrasting background for a photograph; alternatively black paper can be inserted into the bottle.

## **13. FINGERPRINTING CADAVERS**

The problem of obtaining fingerprints from a dead body occurs when a corpse is found without means of identification or other clue to identity. The technique to be employed depends upon the stage of disintegration which the body has attained. In some of the methods described it is necessary to sever tendons or amputate the fingers. The services of the surgeon performing the autopsy should be enlisted for such procedures.

### **Before Rigor Mortis**

The fingers should be cleaned with alcohol, hot water, or an antiseptic soap solution, and thoroughly dried. A fan will be found helpful for drying. The



**Fig. 51. Equipment for fingerprinting dead persons.**



joints of the fingers and the wrist should be exercised until the fingers are pliable. The curved spoons shown in Fig. 51 can be used for inking and printing. The finger is first pressed against a spoon containing the inked pad and then against a spoon in which the paper is inserted. Each finger is inked and printed separately. In the absence of any special spoons, the fingers may be inked with a rubber roller and pressed into a shoehorn into which slits have been cut for inserting the paper.

### After Rigor Mortis

If the fingers are contracted and not pliable, vigorous exercise of the joints will usually render them pliable. Some authorities recommend the cutting of the tendons at the wrist or at the fingers. Soon after rigor mortis sets in, the skin of the fingers begins to shrink and the fingers take on a collapsed appearance. In order to obtain successful prints it is necessary to inflate the fingers by injecting some substance beneath the skin by means of a hypodermic syringe. Among the substances recommended are hot water, air, melted paraffin, vaseline, glycerin, and glycerinated gelatin. The injection is made either at the tip of the finger or below the first joint. When the fingers are sufficiently inflated the fingerprints are taken in the manner already described.

### Advanced Decomposition

After several days of decomposition have passed, the methods described above are usually inapplicable. Ordinarily the skin should be removed from the fingers and immersed in formaldehyde. The skin is then placed over the operator's finger, pressed against the inking pad and rolled on the paper. Sometimes it is necessary to boil the amputated fingers in order to remove the skin properly. When decomposition is far advanced, an x-ray technique may be employed as a last resort. The surface is coated with bismuth subcarbonate, lead carbonate or barium sulfate and a radiograph is made (Fig. 52).



Fig. 52. Radiograph of a finger, outlining the friction ridges.

## TRANSFER METHODS FOR FINGERPRINTS

### 14. USE OF "LIFTING" METHODS

It will often be found desirable to transfer a fingerprint from one surface to another. This process is called *lifting* the fingerprint. The lifting of prints is ordinarily done for the purpose of preserving the original print in a permanent form. Sometimes, however, lifting is advisable in order to make a good photograph possible. A print on a curved polished surface is sometimes difficult to photograph because of reflections and also because of the distortions which occur



in the projection of the curved surface as a plane image on the photographic plate. This latter defect will not, in every case, be remedied by the lifting method but the print may perhaps be more easily studied after lifting.

The usual precaution of a good photograph should first be taken. Only after the investigator has developed the negative and assured himself that he has a satisfactory photograph, should he attempt to lift the print. If the print is found on some portable object which can be retained as evidence, this object should be removed to the laboratory. It should not be expected that a print can be accurately removed from every curved surface. In transferring a print from one surface to another the operator is endeavoring to roll out the curved surface on a plane. In differential geometry it is shown that only a restricted class of surfaces can be rolled out on a plane without tearing or stretching. Such a surface is called *developable*. A cylinder is a developable surface; a sphere is not. Hence, when a print is lifted from the curved area of a door knob or from the handle of a car door, the lifting cannot be made to fit the surface perfectly; the resulting print on the tape has suffered distortions and the representation is not a true one.

Before any of the following methods are used to lift a print, the operator should first experiment by placing a print on the surface and attempting to lift it.

It will be found that black powder is superior for lifting purposes. White powders have a tendency to be dissolved in the tacky surface of the lifting material and to become invisible. (Some manufacturers, however, offer special white powders which, they claim, are made to avoid this difficulty.) Hence, on surfaces such as chromium-plated parts of an automobile, where either powder may be used and where it is known in advance that lifting is desirable, it is preferable to use a black powder.

If it is necessary to make photographs from a lifted print, the photographer should bear in mind that when the lifting material provides an opaque background he is photographing a mirror image of the original print. Thus the negative should be printed from the reverse side. If the lifting material is transparent, the lift can be reversed and photographed by means of transmitted light. Sometimes, however, a transparent material such as Scotch tape is fixed to white paper, thus needing no reversal in printing.

## 15. RUBBER LIFTERS

A rubber lifter is a sheet of tacky rubber with a celluloid protective strip which clings to the rubber. The lifters are provided in black and white. The surface is first powdered and photographed. The celluloid cover is partially stripped from the surface, and the exposed end of the tape is held on one side of the print with one finger. The lifter is then rolled slowly over the print and pressed against the print with a finger. The celluloid cover is replaced by placing the lifter face up, holding the end of the cover taut and pressing the cover carefully but firmly against the rubber. Caution should be exercised to avoid air bubbles.



## 16. TRANSPARENT TAPE

A wide roll of transparent tape provides an excellent lifting material which is in many ways superior to the rubber lifter. One end of the tape is held taut and pressed down over the print (Fig. 53). The tape is removed by lifting until it is well clear of the position of the print, with the end still adhering to the surface. The tape is then cut on the side of the print near the roll. The section bearing the print may then be lifted entirely from the surface and pressed on to a celluloid cover.



Fig. 53. Lifting a print with transparent tape.

## 17. IODINE-SILVER METHOD <sup>17</sup>

In the case of greasy fingerprints on a smooth surface, it is frequently found that dusting with powders is useless because of the resulting smudging. The print can, however, be developed by fuming with iodine. The iodine image may be transferred in the following manner. A thin sheet of silver with a carefully prepared smooth surface is pressed against the iodine image for ten seconds. The silver sheet is then exposed to sunlight or photoflood lamps until the print darkens to a strong black. Several transfers can be made from the same print. This method can be used on sized paper, mirrors, greasy objects, cotton, and silk surfaces.

## 18. PHOTOGRAPHIC PAPER (WEBER PROCESS) <sup>18</sup>

In this process the print is dusted with a suitable powder; a sheet of photographic paper is then pressed against the print and developed to give an image of the print. The powder selected is a mixture of potassium ferricyanide together with a fingerprint powder chosen for color. The print is developed with the resulting mixture, excess powder being carefully dusted away. The photographic



paper is first immersed in water and blotted with filter papers. It is then pressed against the print in the outlines of which now lies potassium ferricyanide, which reacts with the silver chloride or bromide of the paper. The silver chloride (or bromide) changes to silver ferricyanide and potassium chloride (or bromide) where the paper has come into contact with the print.

When the paper is immersed in a photographic developer, the silver chloride is developed into free silver, producing a dark tone, except in the area of the print, where the silver ferricyanide will leave a light outline. The paper is fixed, washed, and dried in the usual manner. The paper may then be used as a negative to print additional copies.

The choice of powders is of great importance. The powder selected must on being mixed with potassium ferricyanide still possess the qualities of a good fingerprint powder. The potassium ferricyanide should be dried and ground very fine (200 mesh) in a mortar. When the print is on a light background, a mixture of 66 per cent wood charcoal and 34 per cent potassium ferricyanide has been recommended by Weber. On a dark background, mercury with chalk powder and potassium ferricyanide in the same proportion are effective. A greater percentage of potassium ferricyanide may be found more effective in these powders.

The authors have found the following adaptation of the Weber process to film quite useful. A mixture of 10 per cent fingerprint powder with 90 per cent potassium ferricyanide is brushed on the fingerprint. A piece of contrast process film,  $2\frac{1}{4}$  by  $3\frac{1}{4}$ , is moistened on the emulsion side in the following manner: A wad of cotton is immersed in water and squeezed until the water is expressed; it is then drawn across the film several times. The film is now laid over the print, emulsion side down. A roller is passed lightly over the film. The film is now placed in a high-contrast developer at 75 F for twenty seconds. It is then fixed in the usual manner. A developer such as Agfa 9-D will be found most satisfactory.

One of the great advantages of the Weber process lies in the fact that white powder prints may be successfully lifted. Black rubber lifters are usually ineffective because they dissolve most powders. The use of paper or film offers an excellent solution to this problem. Another important advantage is in the elimination of any necessity for transparencies. The negative (paper or film) is correct for any print; i.e., it will need no reversal for tones or position and may be printed in the usual manner. Regardless of the original color of the powder or background, a black print on a white background will be obtained.

## 19. PHOTOGRAPHIC FILM (HARRISON PROCESS) <sup>19</sup>

In this process the print is dusted with a powder which is a photographic developer. A photographic film is pressed against the print and then peeled off. It is then treated with ammonia and water vapor to give the proper alkalinity to the developer which lies on the film in the print outline, and development takes place in this area. The film is fixed in hypo, washed, and dried in the usual



manner. It is now clear except in the area of the print and can be used as a negative. A transparency must also be made, because the original negative will give a white print.

The powder used in this process consists of two parts amidol to one part pyro. It must be ground fine and carefully dried. Since it is hygroscopic, care must be taken to protect it from moisture. When not in use it should be kept in a tightly corked brown bottle in a desiccator.



Fig. 54. Friction ridges. A projection photograph made from an impression on transparent film.

The print is dusted in the usual manner. On dark backgrounds the powder yields a white print on dark. For light backgrounds the powder may be darkened by exposure to sunlight so that it can be examined visually.

A sheet of photographic film is now breathed upon (sensitive side) for about half a minute and pressed against the print gelatin side down. The film is carefully lifted and may be developed at any time later.



To develop the film, concentrated ammonia is heated in the hood and the film held over the vapor until the print is outlined on the back of the film. The film is then fixed and washed. A transparency is made from this film and then printed as usual.

## **POROSCOPY**

### **20. THE VALUE OF POROSCOPY**

In a preceding section on fingerprints, it was mentioned that the friction ridges of the fingers or palms were indented by pores, which are the mouths of sweat glands. Like the friction ridges themselves, their shape and relative location are immutable. The epidermis consists of two layers. The friction ridges lie in the outer layer. Their pattern, however, is formed in the lower layer. Only severe injury can obliterate the friction ridges. They cannot be altered or replaced by a different pattern. Similarly, the pore structure, which is an integral part of the friction ridge design, cannot be altered.

The pore pattern has the necessary qualities of an identification medium: the structure is invariable during a person's life; the distribution of the pores in a given pattern is capable of infinite variation; thus, the danger of the occurrence of pore patterns identical in two persons is sufficiently remote.

Poroscopy was first practiced by Edmond Locard,<sup>20</sup> the famous French criminologist. In 1912 Locard's identification of a pore pattern on a rosewood box led to a conviction. Locard considered that the comparison of pores lends additional proof to fingerprint cases where an insufficient number of characteristic points has been found for complete identification.

It will be found that the examples offered in the study of poroscopy are usually cases where the pore patterns are supplementary to the ridge pattern in their use for identification. The ridge pattern in most of these examples is sufficiently detailed to offer reliable identification. An ideal case of poroscopy would be one in which the ridges found were too few in number and too common in design to justify identification by comparison. In such a case the presence of a large number of pores would offer the only reliable proof. Poroscopy would also be helpful as additional evidence in partial palmar prints, since the palm by itself is not given the same weight in evidence as the fingerprint.

No system of classification of pores is in use today. The criminologist is dependent on the apprehension of a suspect for comparison. Having the suspect, he prepares a pattern of the friction ridges and pores. A good knowledge of finger and palm prints would lead him to the general location of the area in question. The comparison of the pore pattern is then made.

### **21. THE PORE PATTERN**

An examination of an impression of pores will reveal that they differ in size, shape, and position with respect to the ridge boundaries. Locard puts their size at from 88 to 220 microns. Their number along a ridge varies from 9 to 18 per



centimeter. In an area of four or five square centimeters approximately 1000 pores will be present.

In any analysis of a pore pattern, all these characteristics must be given consideration. Individual pores must be compared in approximate size and shape. A comparison microscope or photographic enlargements are useful for this purpose. Many characteristics of shape will suggest themselves. Some pores are open on one side of the ridge; the bounding ridge areas will form significant designs; the number of pores in a given length will be found to correspond. The relative positions of widely separated pores should be carefully considered. One method of doing this is to select six or seven pores, fairly well separated and easily identifiable — pores open on the ridge, for example. On a photographic enlargement connect the centers of these pores by lines so as to form a polygon. If this is done to the accidental impression and the known impression of the suspect, the congruence of the two polygons will be quite convincing. Another method would be to compare the negative (or a transparency) of the impression with the negative of the comparison print by superimposing the two.

## 22. PROOF IN PORE PATTERNS

What constitutes certain identification in poroscopy? The answer to this would be the same if the question were asked in reference to fingerprints: convention and experience — convention because of the influence of courts; experience because of the probability of error in superficial examinations. An adequate experiment to solve this difficulty would involve endless labor. According to Wentworth and Wilder: "Mathematically the positive establishment of some 20 to 40 pores should establish a complete identity for the two duplicate areas; yet where a much larger number of details is obtainable, one should use his full opportunities, and make the comparison cover some hundreds of pores, or, if so many are not available, all there are."<sup>21\*</sup> A good case could be made out for the use of the polygon method as a convincing proof. The ultimate appeal in lieu of experiment must be made to the common sense of judge and jury. Theoretically, one might follow the lines indicated by the laws of probability in relation to the relative positions of individual pores in a pattern (Chap. 45). If one can assign some numerical value to the probability of one pore's being in a certain relative position, and another numerical value to the probability of another pore's being in a certain position relative to the first, one can assign the product of these two values to the probability of finding two such pores so located. For example, if five characteristic pores are selected and the probability of finding any such pore in its position is  $10^{-2}$ , then the probability of finding five such pores is  $10^{-10}$  or one chance in ten billion.

## 23. THE ACCIDENTAL PORE IMPRESSION AT THE SCENE

At the scene of a crime, pore impressions will usually not have significance until the possibility of fingerprints has been exhausted. If no fingerprints of

\* From *Personal Identification* by B. Wentworth and H. H. Wilder, 2nd ed., copyrighted 1932, by T. G. Cooke, The Fingerprint Pub. Assoc., Chicago.



value are found, then partial prints should be examined for the presence of pore patterns. This should first be done with a magnifying glass or, better, a Greenough binocular microscope. It is not often that a good pore pattern is found.

Care must be exercised in developing pore impressions. Iodine fuming is recommended for impressions on glass. Osmium tetroxide is recommended for developing pore impressions on paper, because of its capacity for disclosing fine detail.<sup>22</sup> A powder such as lead carbonate or mercuric oxide is used on other surfaces. The impression should not be powdered in the usual manner. The powdered brush should be held over the impression, and by gentle tapping the powder will fall on the impression. The excess can be removed by means of an atomizer. Fingers which are bloody or covered with some foreign substance will not yield good impressions because the pores will be filled with matter.

#### 24. MAKING A PORE IMPRESSION OF A SUSPECT<sup>23, 24</sup>

The following method devised by Maestre and Lecha-Marzo, Spanish dactyloscopists, has been recommended. The materials are carefully melted by applying gentle heat to the container in which they are to be mixed.

4 g yellow wax  
16 g Greek resin  
1 g spermaceti  
5 g tallow

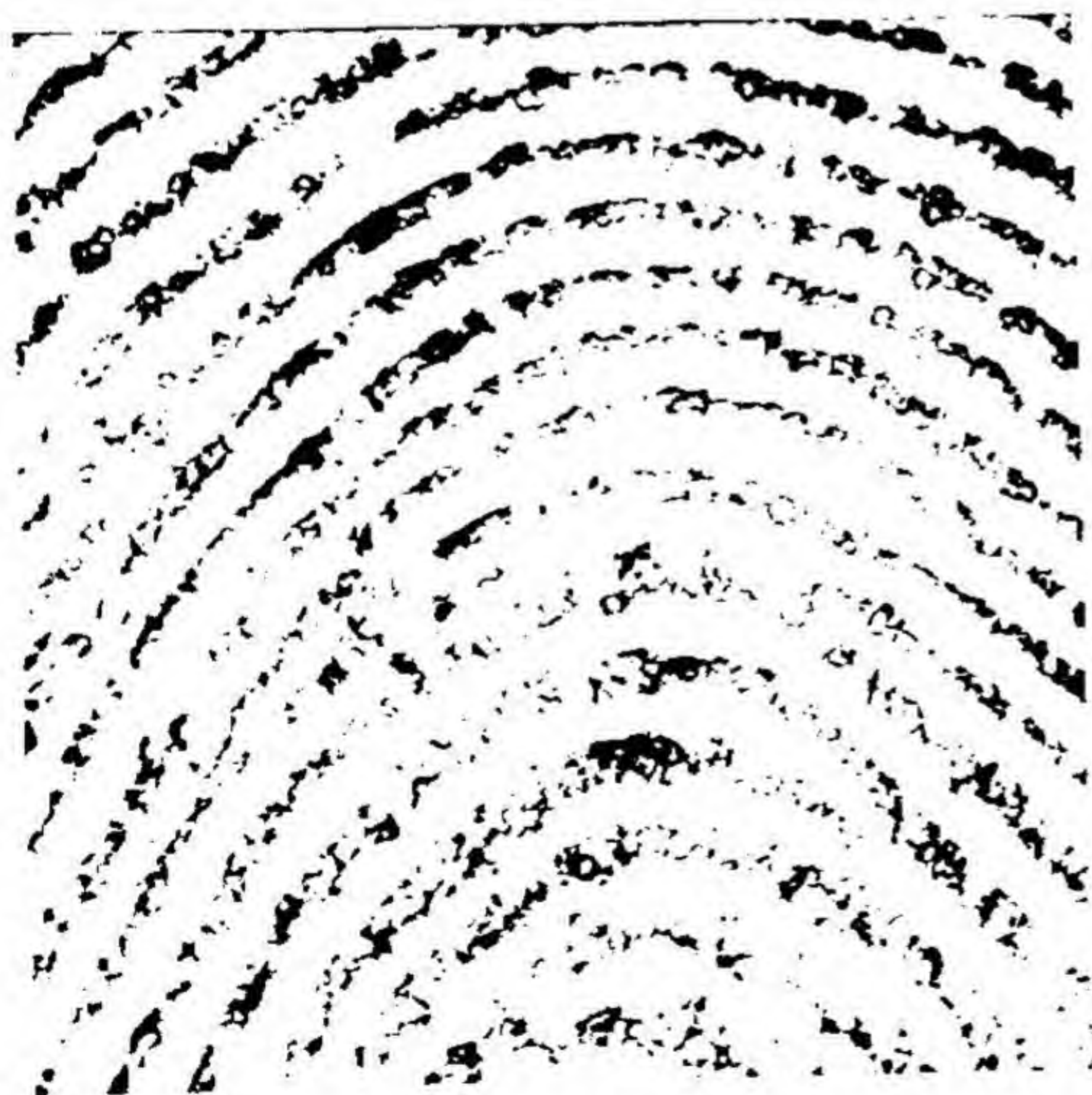


Fig. 55. Pores visible in a fingerprint developed with powder.

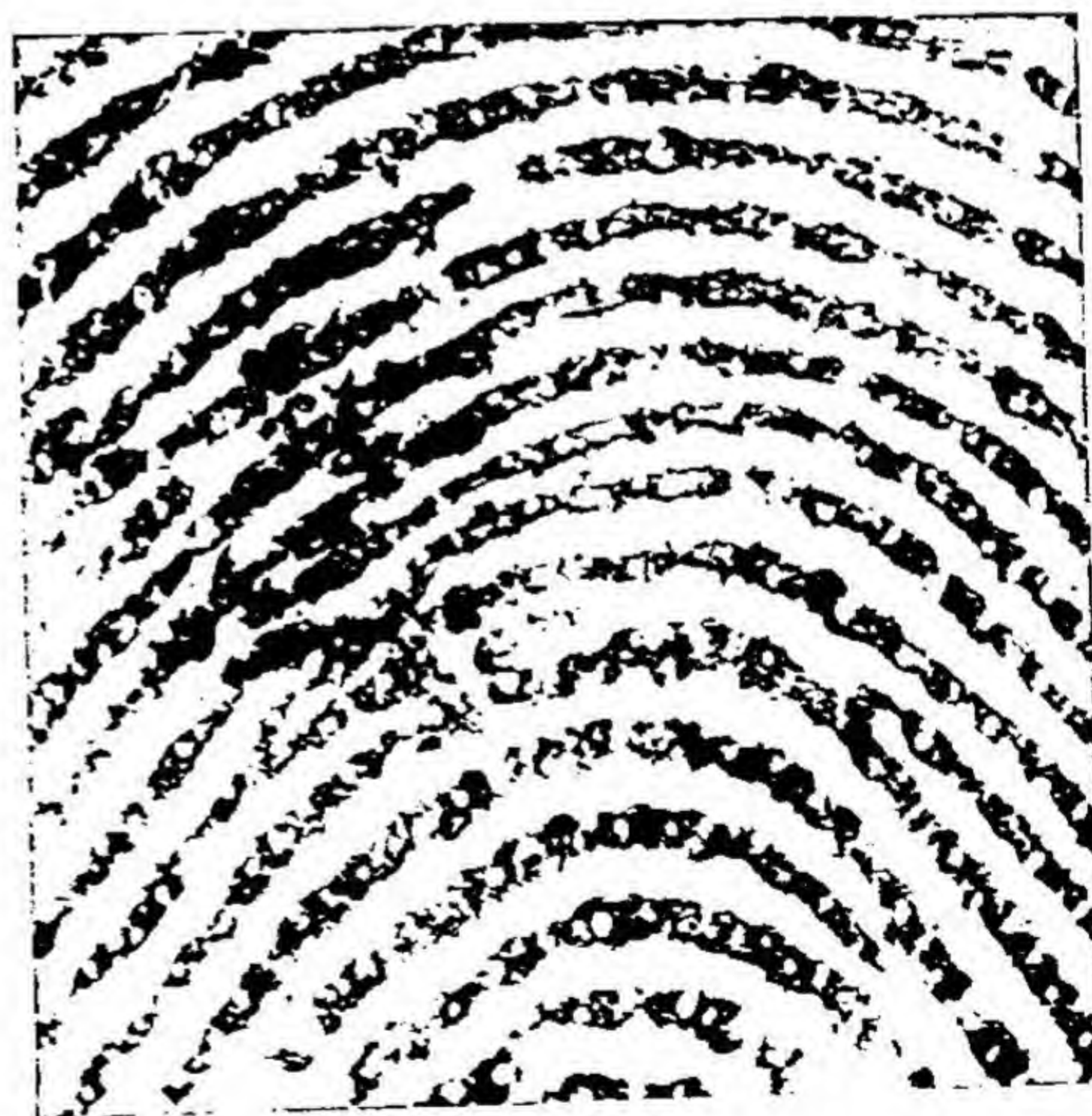


Fig. 56. A comparison print for Fig. 55. This was made with fingerprint ink.

This solution is placed in a flat container to solidify. The finger is cleaned with ether or xylol and rubbed on the surface of the mixture. It is then placed care-



fully against a highly glossed paper or celluloid. Cobaltic oxide is used to color the print. The print may be fixed with the following solution:

25 g gum arabic  
10 g alum  
5 g formalin  
300 ml water

Although ink is not recommended by authorities for pore impressions because of its tendency to fill the pores and thus spoil the outlines, the authors have found that fair impressions can be made with ordinary fingerprint ink (Fig. 56).



Fig. 57. Palm print apparatus.

In photographing pore impressions, the choice of a camera should be influenced by the need of subsequent enlargement. For a proper examination an enlargement of from thirty to fifty times is desirable; hence a camera, film, and developer capable of a great definition should be used. A 35 mm type camera with Panatomic-X or a similar fine grain film is recommended. In photographing the accidental impression, the methods of Chapter 16 will be found useful.

### EXERCISES

1. Place a fingerprint on each of several knives. Develop the prints using different powders, such as black powder, gray powder, white powder, red powder, etc. Compare the detail developed in each print. This experiment must be conducted several times to yield instructive results because of the difficulty of placing equally good prints on each knife.
2. Repeat the experiment using glass surfaces.
3. Using a large glass surface develop prints by means of the duster, brush, and atomizer. What differences are there in the quality of the developed prints, the time



consumed, and the relative ease of use? What recommendations would you make for the use of each?

4. Using a duster and prints on a polished wood surface determine the effects of careless development by using light and heavy strokes in the development of alternate prints. Develop one or two prints with a careful, light touch and examine the prints; continue with vigorous strokes and note any disappearance of detail. Examine the prints with a low-power binocular microscope at each stage.

5. Place fingerprints on about ten sheets of paper. Place two sheets of paper in each of five envelopes on which has been inscribed the date. After two days, remove one envelope and develop one sheet of paper by the use of powder; use the iodine fuming method on the other. Compare.

6. After another week, select another envelope and repeat the above procedure. Compare with the results obtained after a few days. Fix the iodine prints by one of the methods described in the text.

7. Select another envelope at this time and use the osmium tetroxide and silver nitrate methods. Compare with the results from 5 and 6.

8. After one month select another envelope and repeat the procedure of 7. After comparison, remove the silver nitrate prints with mercuric chloride.

9. Repeat 7 after three months. Use hypo to fix the silver nitrate prints.

10. Place several sets of fingerprints on a smooth surface. Develop these prints using appropriate powders. Lift the prints by means of each of the following transfer methods: (a) rubber lifters, (b) transparent tape, (c) photographic paper, and (d) photographic film. Identical prints should be lifted in each case. Compare the results. Compare the methods in regard to the quality of the lifted print and the practicability of execution.

11. If silver sheets are available, an experiment can be performed on greasy fingerprints. It will be found that many apparently greasy fingerprints are susceptible of powder development; hence a grease such as vaseline should be used so that powder methods will be precluded because of smudging. Place such a set of prints on glass. Transfer the prints by the iodine-silver method.

12. Examine a finger under a hand magnifier or microscope to observe the presence of pores in the ridges.

13. Under a microscope examine a fingerprint made with ink at about 40X. Comment on the pore pattern.

14. Place impressions on various kinds of surfaces such as glass, metal, etc. Examine these impressions with a hand magnifier for pore patterns. Develop the impressions with a powder and examine again.

15. Place impressions on glass slides and develop by iodine fuming. Examine under the microscope. Compare with an impression on glass developed with powder.

16. Prepare an impression using the method given in sec. 24. Compare with the impressions made on the glass slides.

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# CHAPTER 9

## FOOT AND TIRE IMPRESSIONS

### PLASTER CASTS

By far the best means of studying an impression in mud, snow, or other surfaces is that of the plaster cast. Quite frequently, a properly made cast will offer much more information to the eye than the impression itself. Shoe and tire impressions are not infrequently found in connection with crimes, even in large cities. Tool and weapon impressions at times will also provide good subjects for plaster casts.



Fig. 58. The foot impression before casting.

#### 1. BEFORE CASTING

A photograph of the shoe or tire impression should always be made before a cast is attempted. A ruler should be placed at the side of the impression and the photograph made with the plate of the camera parallel to the surface bearing the impression in order to avoid distortion. A photograph should also be taken from the angle which reveals the most detail. The 35 mm camera is admirably adapted to this kind of work, particularly when there are many footprints to be photographed. Panchromatic film should be used for footprints in earth. Process film will supply the necessary contrast for footprints in snow and sand where there is only a very small range of light intensities; however, low-contrast film should also be used to avoid possible errors.

The impression should be carefully measured with compasses and ruler before it is touched. The distance from the front of the sole to the rear of the heel, the length of the heel, the width of the front of the heel, and the width at the



widest part of the sole should all be measured. The nature of the soil bearing the impression must be carefully studied in conjunction with the weather which has prevailed since the print was made. In some soils such as clay, the original impression may suffer considerable contraction and distortion on exposure to sunlight or rain.

## 2. MAKING THE CAST

Although various preparations are recommended for casting, it will be found that plaster of Paris of the best grade will give the most satisfactory results. Commercial preparations such as Albastone offer the additional advantage of greater hardness.

A container is partially filled with water. Plaster of Paris is slowly poured into the water until the water can no longer absorb any more. Seven parts plaster



Fig. 59. Spraying the impression with shellac.



Fig. 60. Applying a layer of talcum powder.

to four parts water is a satisfactory mixture. The plaster is then mixed by hand until there are no lumps present. Water or plaster may be added until proper consistency is obtained. The mixture should have the fluid characteristics of cream. When the plaster is poured into the print, it should not be held high above the print, but should be poured from a low level, if possible breaking its fall by means of a spoon. The spoon should be used to spread the plaster evenly without touching the print and to aid in preventing air bubbles from forming.

When the layer of plaster is almost one-half inch thick, small sticks are carefully placed on the plaster to reinforce the cast. A supply of tongue depressors should be at hand for this purpose. The sticks should not extend beyond the outlines of the print. As soon as these sticks have been placed, a second layer of plaster is poured in until the total thickness is an inch or more, depending upon the depth of the impression.

These operations should be performed with reasonable rapidity. The plaster has a tendency to settle to the bottom of the container, leaving only a thin liquid



at the top; hence, it should be stirred before the second layer is poured. If the operator delays too long, he will find the first layer hardening before his cast is complete. The plaster should be permitted to set for fifteen minutes. Plaster of Paris is partly hydrated calcium sulfate  $(\text{CaSO}_4)_2 \cdot \text{H}_2\text{O}$ . On being mixed, the plaster takes up water of crystallization and forms into a hard mass. The reaction is exothermic, and hardening is indicated by the rise in the temperature of the mass.

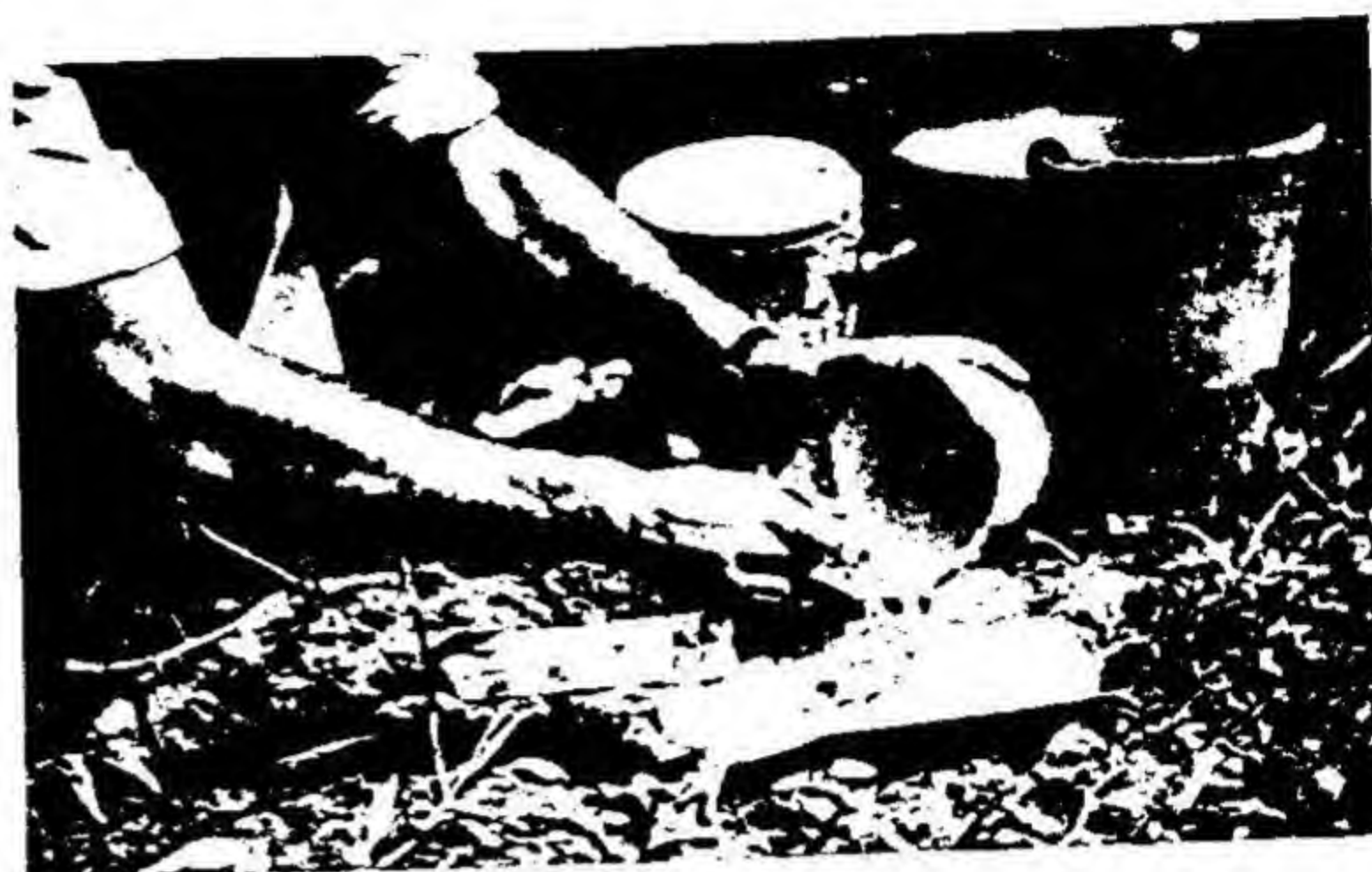


Fig. 61. Pouring the plaster.

The procedure described in the preceding paragraph is not fixed, but must be modified to suit the medium in which the impression is found. Snow, sand, dust, and flour may require different techniques, some of which are given below. It will be found that many of the casting procedures described in various texts survive chiefly because of the dignity which age has given them. In scientific background, most of these recommendations are comparable to cooking recipes, and departure from literal instructions may be contemplated with equanimity. The one rule of value is the following: Before using any casting procedure on an impression in a difficult medium, such as sand or snow, place another foot impression in the medium and make an experimental cast.

### 3. CASTS IN FIRM SURFACES

Earth, mud, clay, and similar substances provide a relatively firm base for making a cast. Their comparative rigidity and cohesiveness render them fairly simple subjects in casting; nevertheless the surface of the impression usually bears detail which may be delicately formed and composed of small, discrete masses. The weight of the plaster may somewhat deform this detail unless certain precautions are taken. To increase the rigidity of this surface detail, a thin layer of shellac dissolved in alcohol is spread on the surface by means of a sprayer of the kind used for spraying insecticides. The shellac is carefully sprayed from a distance of several feet so that the air pressure will not affect the detail of the impression. After several minutes the shellac will have hardened, and a thin layer of talcum powder is sprinkled on the layer of shellac. The plaster is then poured in. When the cast has hardened, the shellac is peeled off. The talcum powder permits the peeling of the shellac without affecting the cast.

### 4. CASTS IN SNOW

It is not possible to give a general prescription for making a cast in snow because the kind of snow and the conditions under which it is found are many and varied. One method which is commonly recommended<sup>1</sup> consists in laying down a thin layer of talcum powder followed by a layer of sprayed shellac. This procedure is repeated twice. The plaster is then poured in with a spoon. Where



snow is near the melting point, however, as in the case of snow on the roof of a heated building, this method may not yield success since the hardening of the plaster is an exothermic reaction. The plaster must be permitted to cool considerably, before it is poured; otherwise it will melt the snow and sink into it. The thickness of the mixture is quite important in these circumstances. After the plaster of Paris and water have been mixed in the usual manner, the solution should be left standing for about five minutes. The thickening of the mixture will adapt it admirably to the purpose. Naturally the mixture should not be permitted to become too thick. The optimum density may be determined by periodically testing the mixture by pouring a spoonful on the snow. When the point is reached where the plaster does not penetrate the snow, it should then be poured in the impression. Another method<sup>2</sup> of plaster casting in snow is to sift a thin layer of the dry plaster over the print and permit it to stand for ten minutes. Another layer is sifted over the print and the print is then given a fine spray of water.

The problem of casting in snow has been approached from a different point of view by Karlmark.<sup>3</sup> Instead of decreasing the temperature difference between the casting medium and the snow, he uses a medium — sulfur — which has an exceptionally poor capacity for heat conduction and a low specific heat. A wall of snow is built around the foot impression and a small hole is made at one end for the entrance of the sulfur. Flowers of sulfur in sufficient quantity (about 5 pounds for an impression) is heated until it is melted. The sulfur is then removed from the heat and permitted to cool until scales appear on the surface. The liquid should be stirred continually throughout the process. A scoop is used to pour the sulfur into the hole through which it flows out on the impression. Five to ten minutes are required for hardening.

## 5. SAND, DUST, AND FLOUR

Several problems arise when a cast must be made in these media. First, the lack of cohesion among the particles presents the danger of losing detail because of shifting under the weight of plaster; second, these substances may be dissolved by the plaster; third, these substances will adhere to the plaster and cannot be washed off. To meet these difficulties, a layer of shellac is first placed over the impression. Considerable care must be exercised to avoid disturbing the powdery outlines. Next the shellac can is removed from the sprayer and a can of light oil is substituted. After the shellac has dried, a thin layer of oil is sprayed over the coat of shellac. The plaster is then carefully poured in with a spoon. In place of shellac Tryhorn<sup>4</sup> recommends a 4 per cent solution of cellulose acetate in acetone.

## 6. HASTENING, RETARDING, AND HARDENING

Sometimes it is desirable to hasten or retard the setting time of plaster. For example, shortening the setting time is necessary in casts of living subjects; re-



tarding is sometimes necessary to provide more time for working on the cast. The following formulas are recommended by Clarke:<sup>5</sup>

*Hastening* — A thick mixture of plaster will set more quickly than a thin one; hence, the addition of more plaster to the mixture will shorten the setting time. One-half teaspoonful of common salt may be used to increase the speed of setting. This should not be used for casts in snow.

*Retarding* — A saturated solution of borax (approximately 23 C) is added to ten parts of the water to be used in making the plaster.

*Hardening* — To give a dried cast greater durability it can be placed in a saturated solution of sodium bicarbonate (23 C), and allowed to remain in the solution for some time. It is then removed and dried. Various other procedures for these purposes are given by Clarke.

## 7. COMPARISON OF THE CAST WITH A SHOE

It is not always a simple matter to identify the shoe of a suspect as being unquestionably the shoe that made the impression at the scene of the crime. The large-scale manufacture of a few pre-dominant brands of shoes gives the defense counsel grounds for establishing a strong doubt concerning the unique correspondence between the cast of the impression and the defendant's shoe. In many cases, the sole of the cast is without characteristics except for the shape of the shoe. The era of cheap shoes has led many people to the habit of purchasing new shoes rather than repairing old ones. An old, repaired shoe is ideal for characteristics. Half soles leave a pattern of nails in the impression and cut the outer edge of the shoe at characteristic angles. In the great majority of cases, however, most of the characteristics will be found in the heel. The trade name is frequently revealed. Marks of wear, protruding nails, and other defects will be helpful in establishing a correspondence.



Fig. 62. Plaster cast of a heel impression.

## FOOTPRINTS AND WALKING PATTERNS

The traditional representation of a detective portrays him in eager scrutiny of the foot impressions which the criminal has conveniently and carefully left behind in the course of his crime. The humor of this characterization has in recent days probably been influential in dissuading the average detective from a proper study of footprints. Another deterrent to the popularity of this study is



the increase in the number of paved streets in cities and towns. The infrequency with which good footprints are found, however, does not gainsay their great value as evidence. Too many cases have been solved in this manner to countenance any mitigation of the worth of footprints by the "practical" detective, whose fund of faith is completely absorbed in quizzing witnesses and suspects.

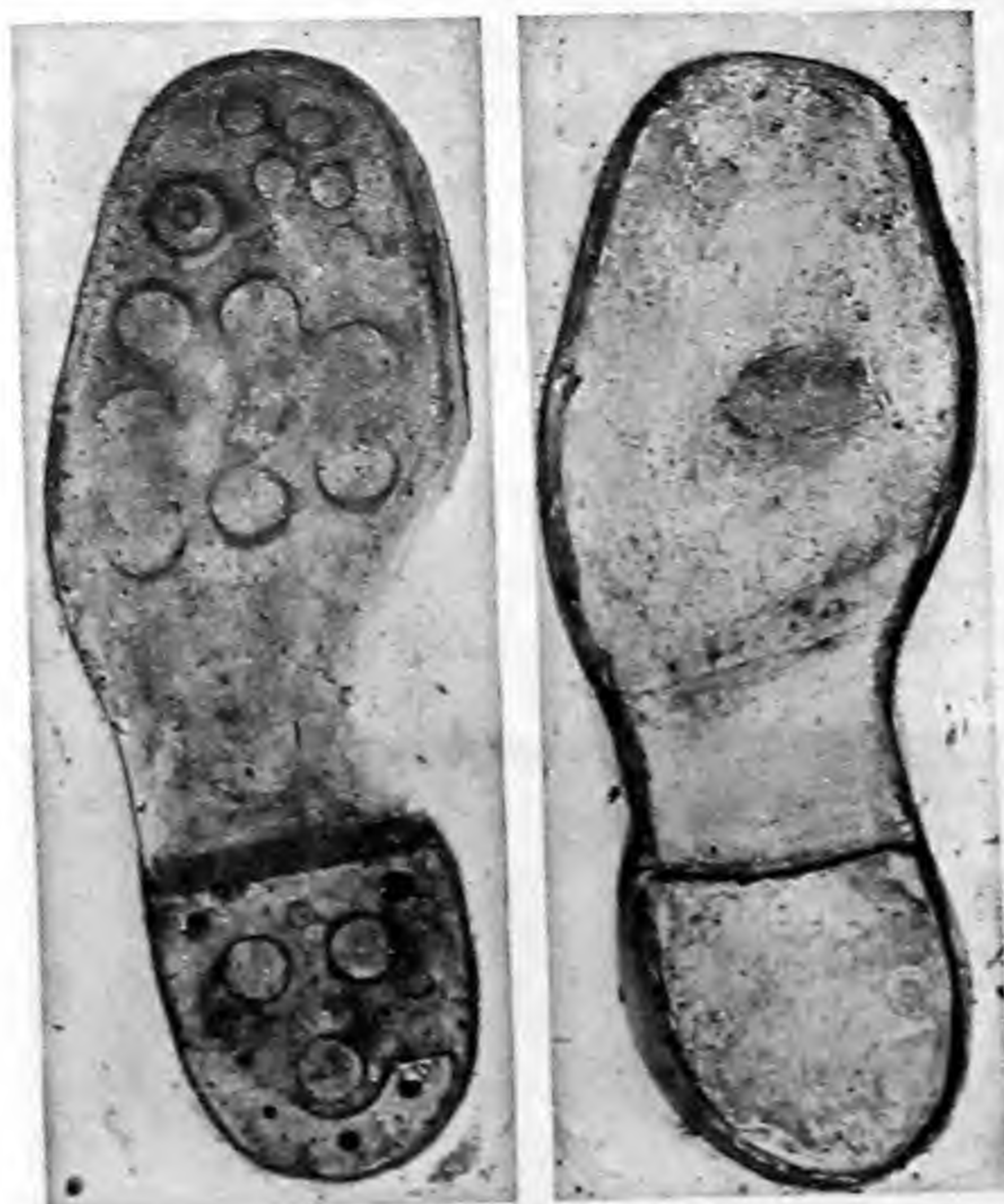


Fig. 63. Plaster casts of shoe impressions.

As in the case of other impressions, the greatest obstacle to the analysis of foot impressions is the confusion contributed to the original situation by the discoverers of the crime: relatives and neighbors of the victim, and even police officers. This gathering may sometimes include thirty or forty persons. It will be assumed here that the investigator has happily reached the scene early and has found a set of foot impressions which he may reasonably expect to have been made by the criminal.

## 8. FOOTPRINTS IN EARTH

We shall take up first the case of foot impressions in earth, snow, or other substance susceptible of receiving an indentation from the foot or shoe; later the case of a print on a smooth surface will be treated. Usually a footprint in earth will not be isolated but will be accompanied by other impressions which will provide a pattern of the owner's behavior in walking.

In order to form a true appreciation of the individual foot impression, it is necessary to study the manner in which it is produced. On walking, a person shifts the weight to the foot at the moment when it reaches the ground. The weight shifts from the interior of the foot to the exterior, producing a slight twist in the front of the impression. When the heel is placed on the ground, the outside part of the back of the heel usually produces the strongest part of the impression. This may be verified by observing the wear on the heels of the average person's shoe. The weight then shifts to the ball of the foot, which produces its impression as the walker drives forward. Finally, the weight shifts to the front of the shoe as the foot leaves the ground. The deep impressions will be made by the heel and toe. In hard ground only these outlines as indicated may be seen.

In studying such impressions the imagination should constantly be employed in their interpretation. If a person is carrying a load or walking rapidly, a deeper cut should be expected in the front of the impression. In running rapidly the heel impression will be deeper than that of the toe; in slow running the opposite



will be true. If the impression is found in mud or snow, a slight shift forward will be expected because the heel does not meet the surface solidly, but slips forward as the surface yields. It should be apparent to the investigator that great caution must be exercised before any conclusion is reached concerning the size of a shoe which should be expected from observing its impressions.

## 9. WALKING PATTERNS <sup>6</sup>

When a number of consecutive footprints are found, it is possible by considering them in relation to one another to deduce some of the characteristics of the owner's manner of walking. Certain lines drawn with relation to the footprints will be found to make fairly constant angles with a chosen line of reference. We shall consider some of these lines.

### Direction Line

The walker is usually progressing toward a given point along a straight line — the *direction line*. This line is a natural choice for an axis of reference. In Fig. 64

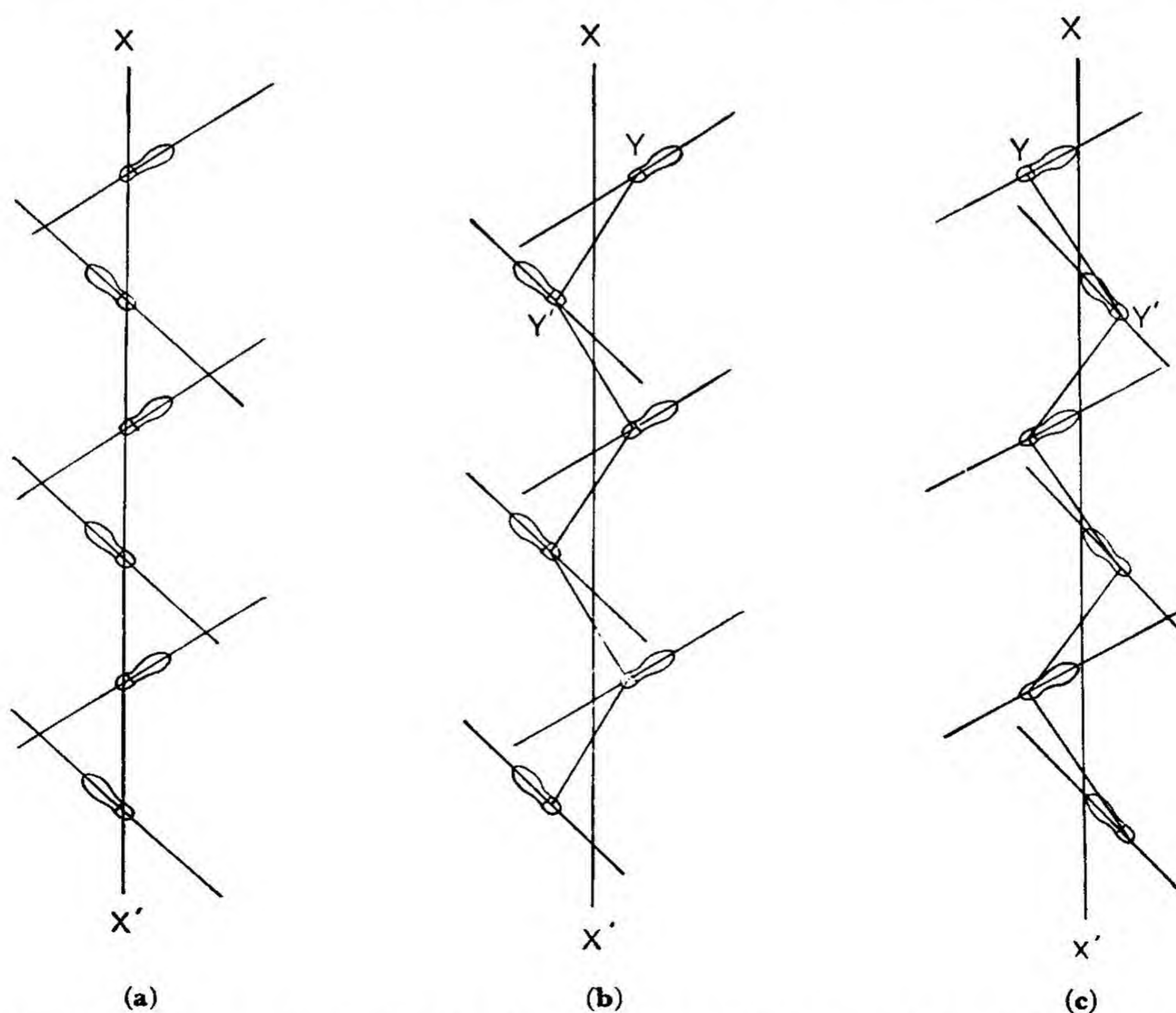


Fig. 64. Walking patterns: (a) the direction line passing through the heels; (b) feet placed at the side of the direction line; (c) feet crossing the direction line.



this line is drawn as  $XX'$ . It is the line about which the footprints are placed symmetrically. Three cases present themselves: (1) Fig. 64a, where the direction line passes through the heels; (2) Fig. 64b, where the footprints are not crossed by the direction line; (3) Fig. 64c, where one foot crosses the other. Case (1) is the normal manner of walking.

### Movement Line

If the mid-points of successive heelmarks are joined by  $YY'$ , as in Fig. 64, we have the line along which the body moves with each step. In Case (1), the normal walk, this line coincides with the direction line. In the other cases this line will cut the direction line at a constant angle which is measurable.

### Foot Angle

If tangents are drawn along the front and rear curves of a footprint at the extreme points, a line drawn perpendicular to these two lines, which are approximately parallel at these points, may be referred to as the *foot line*. It is simply a line of reference in the foot itself. The angle which this line prolonged makes with the direction line may be called the *foot angle*. This angle may be different for the left and right foot. If a sufficient number of prints are present, it will be found that these angles are fairly constant for a person walking at a fixed pace.

### Length of Step

This may be defined as the length of the line joining a mid-point on the heel of one footprint with the corresponding mid-point on the heel of the next. The length of step varies with the size of the person and the rate of walking, among other things. Its value may range from 20 to 40 inches, the average value being about 28 inches. Hesitancy or lack of familiarity with the ground will lead to shorter steps; running or fast walking will produce a longer step.

### Analysis of a Walking Pattern

By means of a tape measure and a large protractor<sup>7</sup> (Fig. 65) it is possible to measure these four characteristics: direction line, movement line, foot angles, and length of step. For a few scattered impressions they will have little importance; for a long series of impressions, however, the four characteristics, carefully measured, will give a highly individual walking pattern that can identify the owner. Taken together with the imprint of the shoe, this pattern may constitute convincing evidence.

It is possible from the walking pattern to make a shrewd guess concern-

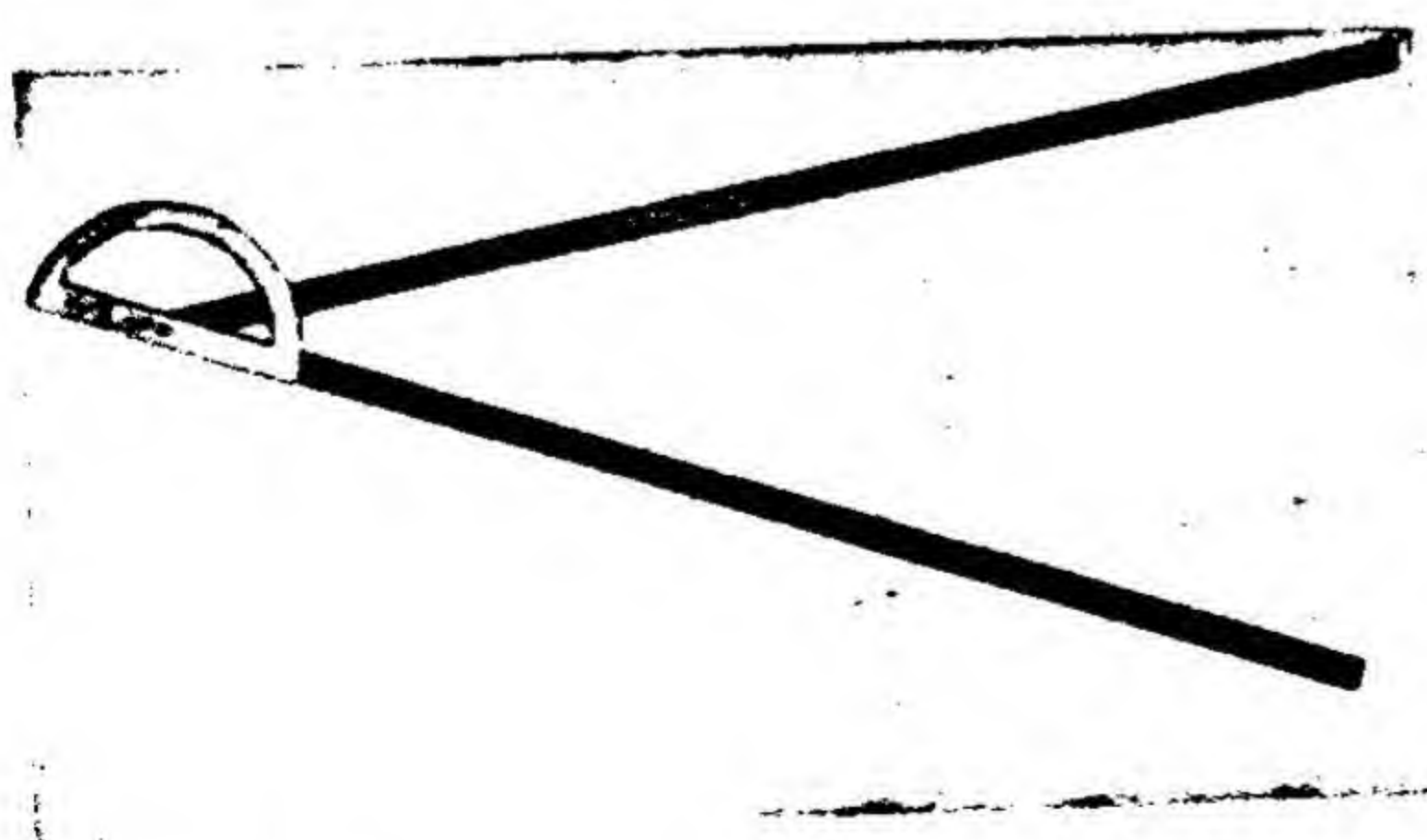


Fig. 65. Protractor for measuring angles in walking patterns.



ing the height of the owner and several of his walking characteristics. Drunkenness, pregnancy, paralysis, age, and various infirmities reveal themselves in walking. However, a study of this aspect of the walking pattern may soon lead to pure speculation without factual basis.

## SURFACE FOOTPRINTS

The surface footprint is produced by the depositing of material on the surface by the foot or shoe. Whereas the foot impression deforms the surface, the

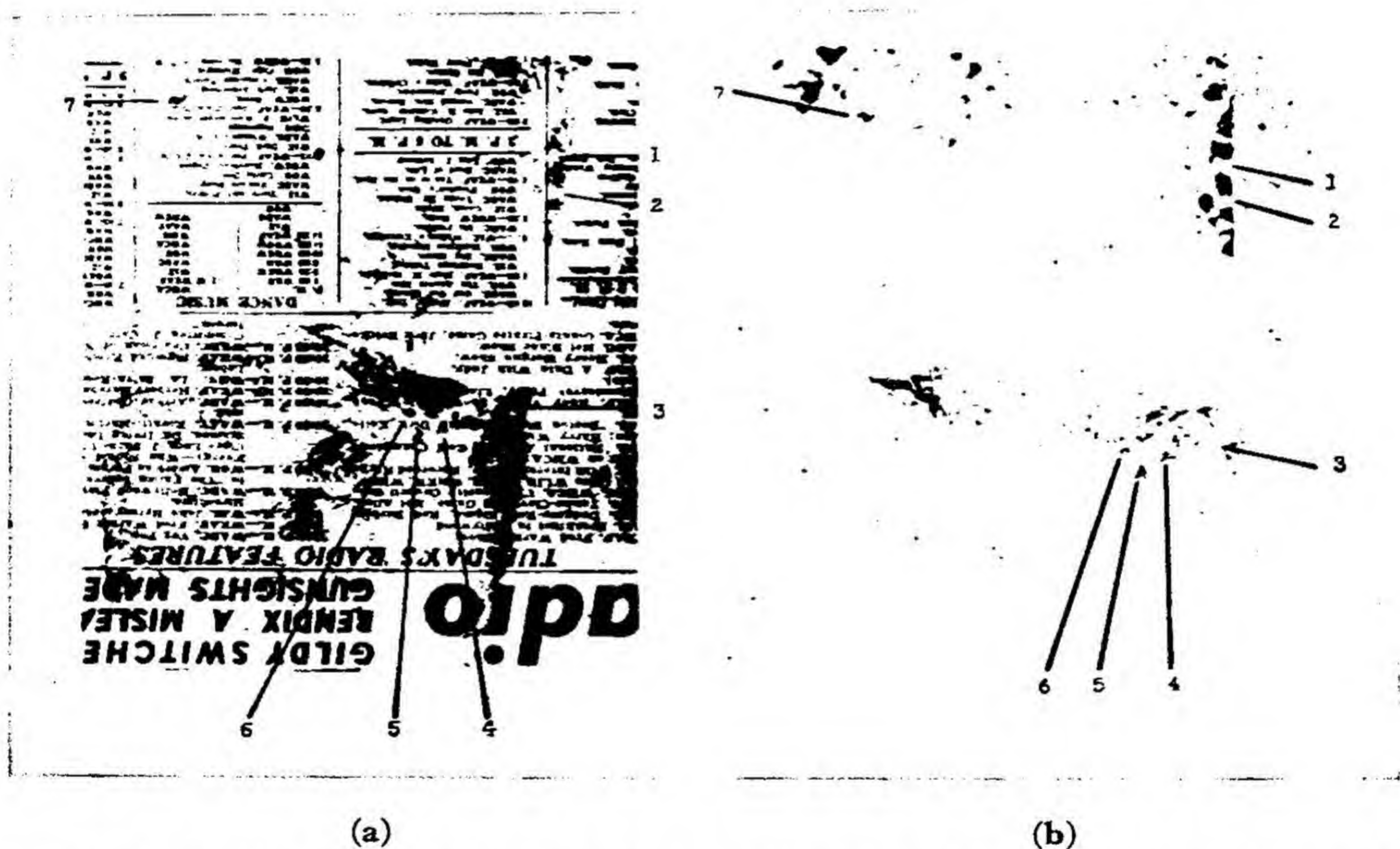


Fig. 66. (a) A footprint accidentally left by a burglar; (b) a comparison print made with the burglar's shoe.

surface footprint merely deposits a layer of dust, liquid, or perspiration upon it. The most common print of this type is a shoe print. Figure 66 illustrates a case of this nature in which shoe prints were made on paper during a safe burglary.

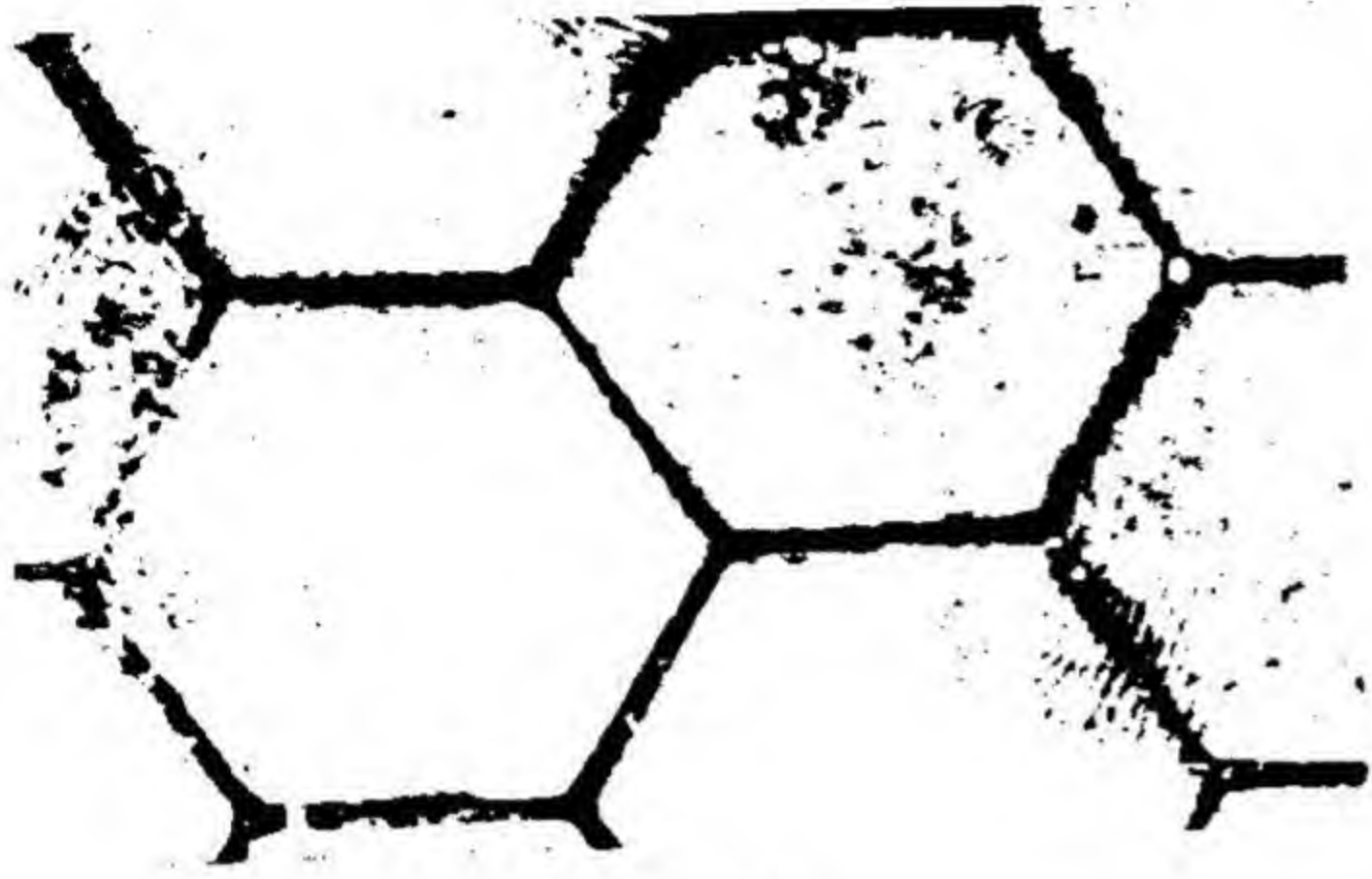
## 10. DEVELOPING SOLE PRINTS

Footprints which can be developed by the usual methods of fingerprint development occur infrequently. Large tile bathroom floors, paper on floors, polished wood and other surfaces can readily receive such prints. The friction ridges on the sole of the foot will leave a deposit of perspiration under the proper conditions. The development of these prints is accomplished by applying the appropriate technique as described in the chapter on fingerprints.



## 11. CLASSIFICATION OF SOLE PRINTS

The permanence of the friction ridges on the sole of the foot suggests the use of sole prints as a means of identification. Wilder and Wentworth<sup>4</sup> have devised a method of classification. Some hospitals make a record of the sole prints of babies as a means of identification. For the purposes of the laboratory investigator it is sufficient to know that the friction skin of the foot is grown in a permanent pattern and that a record of this pattern can be used as evidence where a suspect has been found with an identical pattern. (The remarks of this section are applicable to dermal patterns in general. Palm prints, for example, will be found to occur quite frequently at the scene of the crime.)



(a)



(b)

Fig. 67. (a) Part of a footprint found on a bathroom floor; (b) comparison print of a suspect.

## 12. SURFACE PRINTS OF A FOOT OR SHOE — NO DEVELOPMENT NECESSARY

The dust which accumulates on a shoe or foot frequently is deposited on surfaces such as linoleum, oilcloth, polished wood, etc. A footprint or shoe print found on any surface should first be photographed. Where it is difficult to see the footprint, oblique lighting should be used. Whenever possible, the camera should be placed directly over the print with the lens and plate parallel to the surface. This will at times be difficult or impossible because of the lighting conditions. A scale should be included in the photograph.

## 13. METHODS OF LIFTING

The next problem is that of lifting the footprint. Usually it is not feasible to remove the surface on which the print is found. We shall discuss some of the transfer methods which may be used in cases of footprints found on linoleum, polished wood, and similar surfaces. The problem is simply that of transferring a layer of dust from the one surface to another, which is portable and which may be preserved as evidence.



### Rubber Lifters

This transfer method is similar to that recommended for fingerprints. The reader is referred to Chapter 8 for a description of this method.

### Photographic Film

A large sheet of unexposed photographic film is treated, i.e., fixed, washed, and dried. Before use the gelatin side of the film is moistened or breathed upon until it becomes tacky. If the film is moistened by means of cotton dipped in water, the excess moisture should be allowed to evaporate. With the gelatin side down, press the film carefully against the footprint, smoothing it out with the hand. Peel off the film and allow it to dry completely by laying it on a table, gelatin side upward and weighted or clamped in a film holder to prevent curling.

In the above process the gelatin has been used as a *carrier* for the dust, which is now imbedded in the emulsion of film. The preparatory treatment of the film provides a clear surface for the dust outline. The film should now be protected by means of an envelope or glass frame. At the laboratory the footprint may be again photographed, if the photograph at the scene was not entirely satisfactory. Sometimes the film can be printed in the usual manner (as though it were a negative), thereby giving a white outline of the print in the positive.

### Photographic Paper<sup>9, 10</sup>

This process again utilizes the gelatin of photographic material. In this case the material used is ordinary photographic paper (Fig. 68). If a dark background is desired, such as in the case of a print made from stepping in flour, the paper is exposed, developed, fixed, washed, and dried. If a light background is needed, the paper is fixed, without exposure, washed and dried. Before use the paper is made tacky by the methods already described. It is then pressed against the print, smoothed out, peeled off and left to dry. A photograph of the print on the paper should also be made.

### Cellulose Acetate and Pyroxylin

Another type of carrier for removing a print can be prepared by using a solution of a dissolved, solid, organic material which will harden into a transparent film upon evaporation of the solvent. Pyroxylin, cellulose ace-



Fig. 68. Heelprint in white dust lifted with photographic paper.



tate, collodion, or similar substances may be used. Suitable solvents are alcohol and ether, amyl acetate, etc. Tryhorn<sup>11</sup> recommends the following solution:

Cellulose acetate	4 g
Acetone	50 ml
Benzene	24 ml
Ethyl alcohol	24 ml
Benzyl alcohol	3 ml
Triphenyl phosphate	1.5 g

The solution can be brought to the scene in a tightly corked bottle. It is then transferred to a sprayer and sprayed on the impression until the proper thickness is obtained. The solvent will evaporate. When the substance is completely dry,



Fig. 69. Tire impressions in earth.

it can be carefully removed by cutting and placed between two pieces of glass. Photographs of the lifted prints should be made. The lifted film should also be used as a negative and printed photographically.

This method should be used only on smooth, dry surfaces. Unfinished or tacky surfaces will cause the film to adhere.

## TIRE IMPRESSIONS

The modern criminal finds the automobile an indispensable part of his equipment; consequently impressions and prints of automobile tires are sometimes found at the scene of a crime and, in the absence of fingerprints or other traces, they may form the only clue to the perpetrator. If the tire marks are on



a surface such as asphalt, a photograph should be made; if they are in soil, both a photograph and a cast must be made.

#### 14. DIRECTION OF TRAVEL

If a car is traveling forward in a straight line only the impressions of the rear tires will be visible; going backwards, only the front tires will leave a mark. If the car is turning, all four tires may be visible. It sometimes happens that the car is driven into an empty lot and then backed out along the same tracks. In such a case only the front wheels will leave an impression in the soil.



Fig. 70. Tire impressions in snow.

On asphalt or other hard surfaces oil drops are a good indication of the direction in which the car was traveling. The drops taper toward the direction of travel. On unpaved roads the direction may sometimes be determined by the small masses of dirt which are carried along and thrown on the side by the wheels in the direction of travel. These small masses will taper towards this direction. In hard ground such as earth, mud, or snow, the weight of the wheel may sometimes detach small masses of the material in a serrated or sheaved manner. In order to smooth out this earth the leveling operation would have to be carried forward in a direction opposite to that in which the vehicle was traveling.



## 15. MEASUREMENTS

The distance between the wheels is usually unimportant except to distinguish between passenger cars and trucks. The breadth of the tire mark should be measured since it will have value if the full width of the tire has been impressed on the ground. Almost every tire is marked by indentations or *buttresses* on the edges. These buttresses produce striations in the dirt on the edge of a tire impression in earth. The striations are usually perpendicular to the direction of travel in the plane of the ground. Frequently these regular indentations are the only valuable part of the impression, especially in snow and mud ruts where the tire paths may be composed of hard or smooth ground, but the side walls, being relatively soft, retain the pattern of the edge of the tire. The number of these striations in a given length should be determined. If possible a length of eight feet or more should be chosen. The approximate number of these marks on the whole tire can be determined by the following calculation:

If  $n$  is the number of marks in the measured length  $L$ , then  $n/L = N$  the number of marks per unit length. The number of marks  $M$  that would probably be found on the periphery of the tire is

$$M = NC, \quad (1)$$

where  $C$  is the circumference of the tire.

In the case of passenger cars, the average tire diameter is approximately 27.5 in. Then

$$C = 27.5\pi, \quad \text{and} \quad M = 27.5\pi N \quad (2)$$

Equation (2) is a practical formula which can be employed when tire patterns are found and the width is indicative of a passenger car.

When the tire mark is small, say a foot or so in length, the application of these formulas will result in rough approximations only. The reason for this is the fact that the indentations or buttresses are irregularly placed on the tire (for acoustical and other reasons). Thus, a small number of striations represents the distribution of these marks on a tire in a rough fashion only. Even this approximation, however, will often be found helpful.

## 16. CLASSIFICATION OF TIRES — THE CLASSIFICATION KEY NUMBER

The problem of determining the brand of a tire from a photograph or a cast of its impression is not always a simple matter. One solution is to visit various tire dealers for their opinions. This is practicable, however, only in large cities where a large variety of tire manufacturers is represented. Another procedure is to maintain at the laboratory a collection of tire sections or photographs.

Heindl, the German criminologist, has devised a classification method in which tire patterns are divided into symmetrical and asymmetrical forms. The geometrical shape of elements of the design are then classified into bands, furrows, rectangles, diamonds, etc. Letters are assigned to each type and the result expressed as a fraction. This method has the defect, however, of depending



upon a somewhat arbitrary interpretation of the nature of the geometrical forms.

The authors have found that a more convenient and less arbitrary method of classifying tires may be based on the number of striations or buttresses on the outer edge of the tire. This method would not depend on the central surface pattern of the tire but only on the edge markings. The determination of a *classification key* for a tire, intact and in the possession of the laboratory, is an easy matter. The total number of striations  $M$  on the tire is counted; the outside diameter of the tire is measured, and the circumference is determined. The quotient  $N = M/C$  is the classification key of the tire. With a little work, a laboratory file can be constructed which catalogues the tires of the various manufacturers according to classification key numbers. At the scene of the crime, the number of striations  $n$  in the tire impression is divided by the length of the

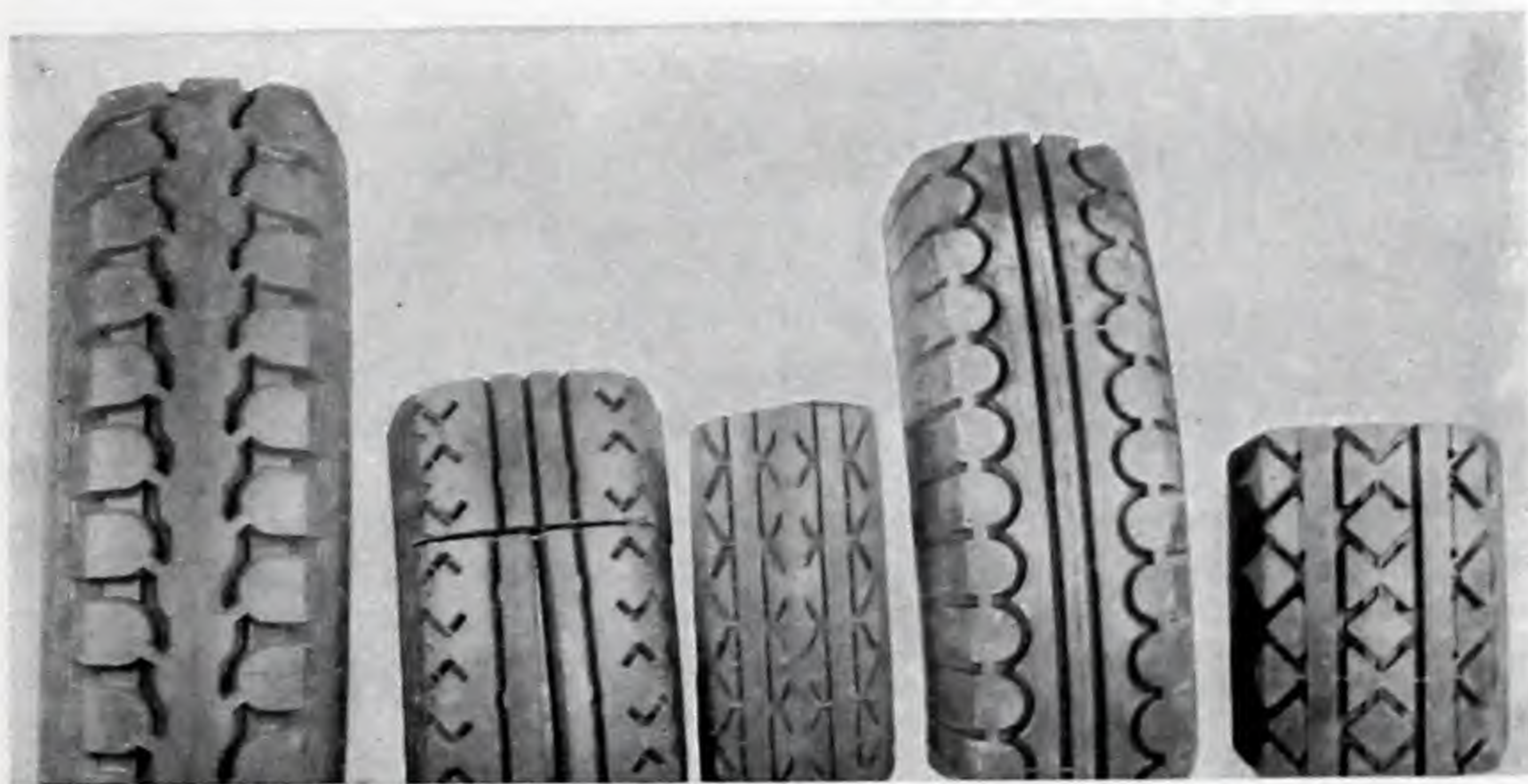


Fig. 71. Tire specimens for reference.

impression  $L$ ; the result is again  $N$ , the classification key. Thus the classification key determined from the tire itself is quite accurate; as determined from the impression left at the scene of the crime, it is possible for the calculated value to vary somewhat from that found in the files. In the laboratory files therefore, tires of which the classification keys are in the region of the one calculated from the impression found at the scene are studied for additional pattern characteristics such as shape and contour of the buttress marks, design of pattern of the central pattern of the tire, etc. From a comparison of these additional characteristics it should be possible to limit to one or two the types of tires which could have made the impression. If no tire is found in the file with a corresponding classification, the approximate number of marks on the tire (which made the impression) can be calculated in the case of passenger car tires by assuming a diameter of 28 inches and using equations (1) and (2). The deviation in  $M$  due



to a slight error in the circumference  $C$  is relatively small. This value of  $M$  will be helpful if it is necessary to search the tire field for other possibilities.

The restriction of using the edge markings of the tire as the basis of classification is justified by the frequency with which these side markings are found in tire impressions in soil where the central part of the pattern is absent, or in cases of "bald" tires. Naturally, cases occur where only the central part of the pattern is present, but in these cases the surface is relatively hard and the tires do not sink in. On the ordinary soil surface, the car will usually sink in to a sufficient depth to give side markings. Moreover, dirt roads are usually marked by

various ruts or wheel tracks which have a small bank, and it is against this bank that the side markings are impressed.

It is not implied here that this method of classification by side markings is completely satisfactory; that is to say, this method will not infallibly point to a specific type of tire as corresponding to the impression. It will, however, greatly restrict the search, and when taken in conjunction with the central pattern, will usually identify the type of tire. A complete tire file should have for each tire a photograph of the central tire pattern and a photograph of the side of the tire. These photographs should be filed under the classification key  $N$ , together with manufacturer's data.

The number 6.00-16 or similar numbers found on tires refer to the outside

diameter of a tire in inches. The number 16 refers to the diameter of the rim; the number 6.00 to width of the tire from the rim edge to the outer edge of the tire. Hence, 6.00-16 would give an outside diameter of 28 inches; i.e.,

$$16 + 2 \times 6.00 = 28.$$

## EXERCISES

1. Apparatus: Sprayer, several pounds of fine grade plaster of Paris, tablespoon, two rubber cups, can of shellac, can of thin oil, talcum powder.

Place a foot impression in moist earth. Lay down a layer of shellac and talcum and make a cast. Make a cast of another foot impression in the same soil without shellac and talcum. Compare the results.

2. Place two impressions in slightly moist sand. On one impression lay down a layer of shellac followed by a layer of thin oil and make a cast. Make a cast of the other impression without any preliminary shellac or oil. Compare the results.

3. Have two persons make walking patterns of about twenty steps in soft earth. Construct the direction lines and the movement lines. Measure the foot angle and the length of step. Determine the average values by using the methods described in Chapter 5. Compare the results in both patterns.

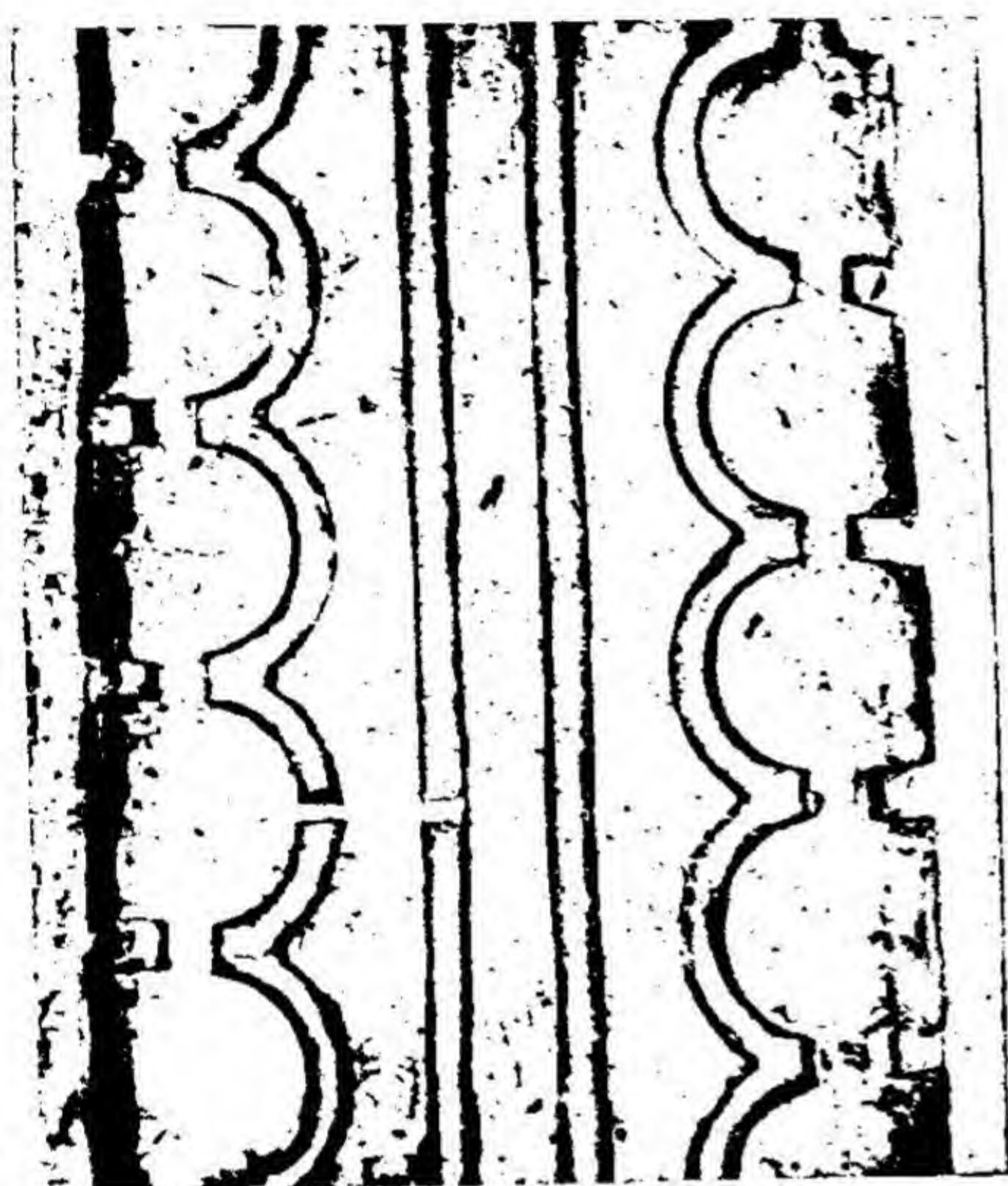


Fig. 72. Plaster cast of a tire impression.



4. Vary the length of steps by walking and running at four different rates. Measure four steps at each rate and compare.

5. Request two persons differing in height by six inches to make a set of foot impressions. Measure the length of step in each case and compare.

6. Select a set of impressions and measure the length of several. Estimate the length of the shoe of the owner. Measure the length of the shoe and compare.

7. Using flour or fine dust make four footprints on a linoleum surface. Apply in order the four methods of lifting given in sec. 13. Compare the results.

8. Prepare a footprint in dark dust on a dark linoleum floor. Experiment with lighting from various angles. Photograph for contrast and minimum distortion.

9. For this experiment an automobile must be available, particularly one that has several different types of tires. Select a section of ground which is receptive to tire impressions. Run the car forward ten feet in a straight line. Alight and notice the impressions. The impressions of which wheels are visible? Back the car carefully over the same track. What impressions are now visible? Drive the car a short distance and turn. Observe the impressions of the four wheels.

10. Select the best of the tire marks and make a plaster cast, suiting the preparation to the soil.

11. For each tire mark select a length of eight feet or more and count the number of striations or edge markings in the length. Calculate  $N$ . Measure the diameter of each tire and count the number of striations on the edge of the tire. Again calculate  $N$  and compare with the experimental results.

12. Restrict your attention to a 14-inch (length) portion of one of the tire impressions prepared as directed in exercise 9. Assuming that this fragmentary pattern (14 inches) is all that is available, determine  $N$ . How does this value compare with that determined from the tire itself? With that determined from the 8-foot length?

13. If the number of side marks or striations found in an impression is 16 and the length of the impression is 10.5 inches, calculate the total number  $M$  of the markings on the tire, assuming an outside tire diameter of 28 inches.

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# CHAPTER 10

## TOOL IMPRESSIONS

### 1. INTRODUCTION

A valuable clue in the investigation of many crimes is the discovery of an identifying mark of the tool which was used in the act. This tool may be the implement which was employed to accomplish the break in a burglary, or it may be the weapon used in an assault. The nature of the tool is usually determined by an examination of the mark or indentation which it has left on some wood surface or on a metal part. If the search for the tool is successful, the investigator is faced with the problem of matching the tool with the tool impression. Sometimes the tool mark will indicate the degree of skill with which the tool was used. In rare instances small particles of metal or paint from the area at which the implement was applied will be found, and a subsequent spectrographic or x-ray diffraction analysis may yield conclusive proof.

The ultimate purpose of a comparison of the tool with the impression is to demonstrate that the impression was made by *this particular* tool. It is not frequently, however, that this can be satisfactorily shown. Ordinarily, the investigator must be content with proving that the impression was made by a tool of *this type*, e.g., by a ball peen hammer of a certain size. The desideratum, nevertheless, should be the identification of the individual tool.

The method of proof in such an investigation is similar to that of a firearm identification. The characteristic marks of the impression are produced by defects in the tool. A test impression is made with the tool, and the characteristics of the test impression are correlated with those of the impression found at the scene of the crime. The greater the percentage of characteristic marks that are common to the two impressions, the stronger is the proof that they were made by the same instrument, since the probability increases exponentially with the number of characteristics (Chap. 45).

Tool impressions may be placed in two classes accordingly as they are made by

- (a) an instrument such as an axe, hammer, or pliers, which touches the area only once in producing the impression.
- (b) an instrument such as a saw or file, which is applied in repeated strokes over the same area.



It is difficult to identify tools which produce impressions of the second class. It is those of the first class with which we shall be mainly concerned.

## 2. PROCEDURE AT THE SCENE

On discovering a tool impression such as a jimmy mark on a window or a hammer mark on wood, the first step should be the photograph. Two photographs should be taken: one showing the background or setting of the impression, e.g., the whole window in the case of a jimmy mark; and another showing the impression alone, i.e., a close-up such as a one-to-one photograph made with a 35 mm camera. A ruler should be included in both of these photographs.

A mold of the impression should now be made by means of modeling clay or plasticine. It is advisable to make two or three molds to insure a faithful reproduction. This mold is a replica of the tool itself. At the laboratory a cast must be made to reproduce the impression. Casting methods for this type of impression are described in Chapter 11.

If it is at all practicable, the surface bearing the tool impression should be removed and taken to the laboratory. The photograph and cast should, of course, first be made *in situ*. At the laboratory, however, these processes can be repeated with greater success because of the advantages of equipment and choice of materials.

## 3. PROCEDURE AT THE LABORATORY

It is assumed that the tool is now available to the investigator for comparison with the impression or its cast. In order to make a comparison it is necessary to produce test impressions with the tool in question. Before this is done, the tool should be examined for any traces of metal or wood which would connect it with the original impression. An examination of the blade of the tool should be made under the binocular microscope for minute particles.

The procedure employed will vary with the type of mark which is being dealt with. We may classify tool marks for this purpose as follows:

- (a) Compression marks, which are produced by a single application of the tool in one area of contact, for example, the impression of a simple blow of a hammer.
- (b) Friction marks, which are a series of scratches or striations produced by pushing a tool such as a screw driver across a surface.

In both cases the mark will vary with the manner in which the tool is used. These variations will be discussed under friction marks since it is in this class that the variations are of greatest importance.

### Compression Marks

A cast of the tool can be made and compared with a negative cast of the impression. These three-dimensional reproductions are excellent for comparison where the impression is relatively deep as in case of a hammer or jimmy mark in soft wood. Where the impression is shallow, however, casting does not always



give satisfactory results. Chisel and knife marks are examples of the latter class of impression.

A photographic comparison should be made next. This can best be done by making an impression with the tool on material similar to that on which the original impression was found. The two impressions can then be photographed together and properly aligned in printing so that the corresponding characteristics can be readily seen. If the original impression has not been removed to the laboratory, the photograph taken at the scene is used for comparison. For the purpose of court demonstration enlargements should be made and lines drawn between characteristics where necessary.

The advantages of both of the above methods of reproduction can be combined in a stereoscopic photograph. For very fine markings a low-power stereomicrograph is most satisfactory. Chapter 18 describes the technique of this type of photography.

### **Friction Marks**

The identifying marks usually left by an axe, wire cutters, or jimmy are a set of parallel striations. Direct comparison of the tool will yield little information. A photograph of the mark found at the scene and a test mark made at the laboratory on a similar material will provide the most effective means of comparison.

In making the test mark it will be necessary to experiment with the tool, applying it at various angles and in different directions. Burd and Kirk<sup>1</sup> have shown that in matching screw driver marks in lead a satisfactory match could be obtained only if the vertical angles at which the tool was applied corresponded within 15 degrees. When the angles differed by 10 degrees a match of 60 to 65 per cent of the lines could be obtained. With a 20 degree difference a match of only 40 per cent was possible. A variation in the horizontal angle between the tool and surface will also affect the striations, pushing them closer together and altering their appearance. A correspondence of horizontal angles within 20 degrees was found necessary for a convincing match. Tryhorn<sup>2</sup> has described the effect of variation of the angle of application on marks made by cutting tools and levers.

The criteria for determining when a convincing match is obtained must be drawn from experience, common sense, and the laws of probability. A perfect line-by-line match is never obtained. A large proportion of lines in each mark should correspond. Burd and Kirk<sup>3</sup> point out that the number of matching lines should be considered in conjunction with their proportion to the total number of lines. Out of 100 lines they consider a match of 60 as constituting an identity, and a match of only 40 as insufficient to justify such a judgment. This precaution is observed because of the fact that two tools of standard manufacture may match in 20 to 25 per cent of the lines. A match of only a few lines, however, will constitute an identity when these lines represent a high percentage of the total number of lines present. For example, if only 10 lines are present and 8 of these match, this number would suffice.



#### 4. MICROSCOPIC EXAMINATION

The characteristics of a tool impression which are of evidential value are usually fine ridges and lines which must be examined in a magnified image for clear perception. All tool impressions should be examined under a low-power microscope of the Greenough binocular type. A comparison microscope is excellently adapted for the purpose. A magnification of 20 or 30X will be found sufficient. Greater magnifications are usually confusing because the relations between marks or ridges are no longer clearly perceived.

The striations in the marks should not be examined merely for general geometric correspondence; the ridges and depressions must be compared individually for contour, depth, and height. The presence of material in the lines which would interfere with their usual formation should be noted. Particles of material which become separated from the surface are sometimes carried along by the instrument, clogging the path which would normally be formed.

The investigator should not be satisfied with visual examination through the microscope; a photomicrograph should always be made. The impressions can be photographed together. If they are photographed separately, care must be taken to illuminate the ridges from the same direction. A low angle of illumination will provide the necessary contrast. In preparing court exhibits enlargements should be made. Notations can be made on the enlargement to indicate corresponding marks. Another method of demonstration is the use of transparencies. An enlarged transparency of each negative is made. When the transparencies are superimposed one set of ridges will be seen to lie exactly over the other set.

A series of measurements under the microscope should also be made. A traveling microscope or a micrometer ocular may be used. The distances between outstanding characteristic marks should be measured in each impression. The correspondence between these measurements will lend additional weight to the evidence.

#### 5. IMPRESSION OF VARIOUS TOOLS

##### Hammers

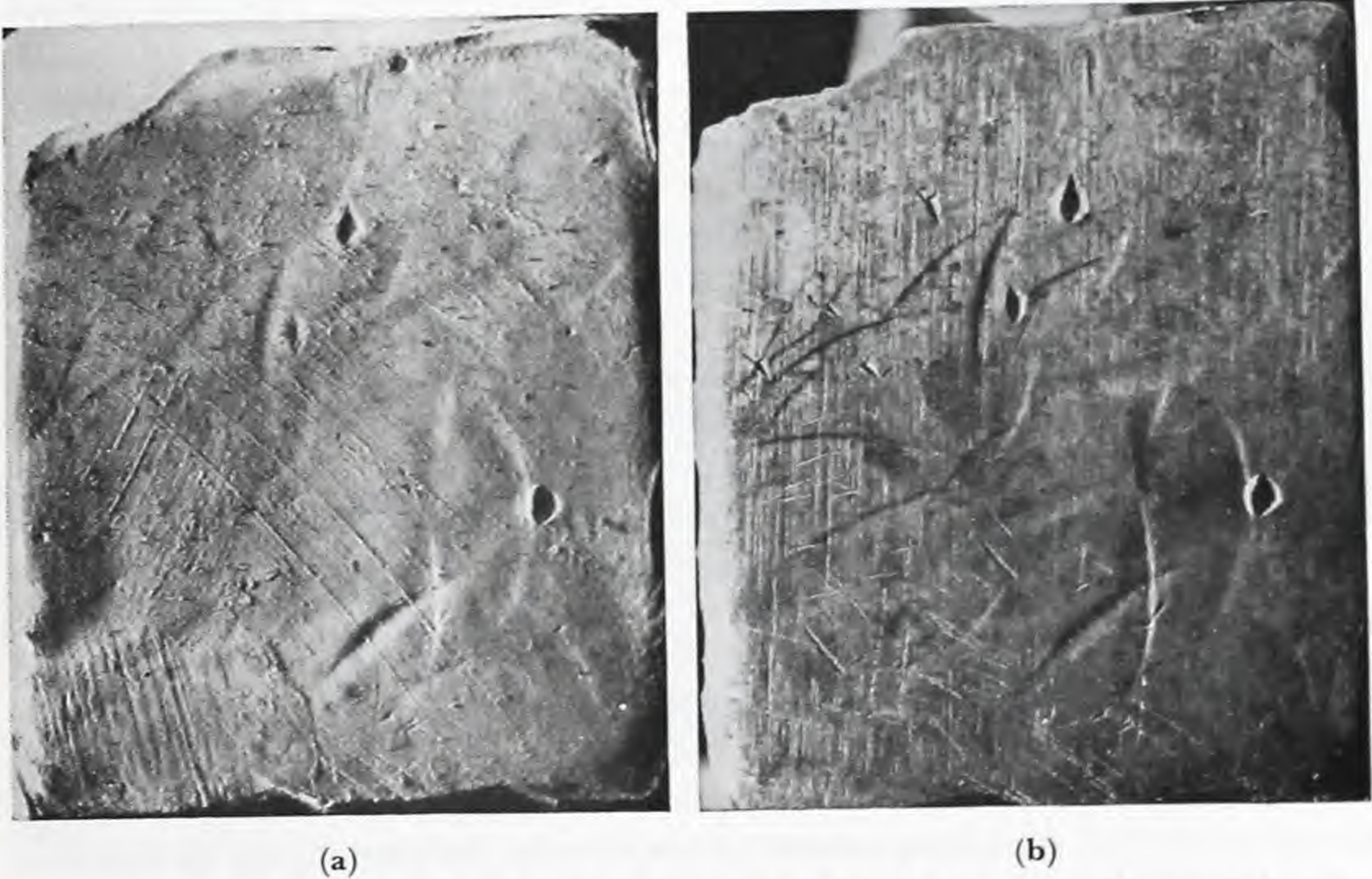
A hammer may be employed in many ways for accomplishment of a criminal aim. It may, first of all, be used in a conventional manner in the construction of some object which will later be of interest in the investigation of the crime — for example, an improvised ladder. Secondly, it may be employed to force entry or to perpetrate an act of sabotage or malicious mischief. Thirdly, it may be the weapon used in an assault. Unless the hammer is new and unused, its face will be variously deformed from striking nails or irregular surfaces. When a surface such as wood or soft metal is struck by the hammer it will bear an impression of the hammer head. In some cases the defects of the hammer will be visible in the impression. The symmetry of the impression will indicate the skill of the user. When a hammer is used by an experienced mechanic, the face of the hammer strikes the surface flush, i.e., along a line perpendicular to



the surface. The unskilled workman strikes the surface at an angle and digs in at the side (Fig. 73).

### Cutting Tools

By these are meant instruments with single blades, such as knives, axes, razors, planes, wood chisels, paint scrapers, etc. Slight nicks in the blades of these instruments due to improper use are quite common. Indeed, the blade of even a new razor will under a microscopic examination of sufficient magnification reveal not a straight line but a series of serrations. When the blade of such a tool is applied to a wood surface, the blade travels along the surface through a distance of an inch or more. The indentations in the blade of the tool leave ridges in the wood along their paths. On examination of the surface a series of lines can be observed. If the tool is used on another part of the surface, the same pattern of lines is reproduced.



**Fig. 73. (a) Plaster cast of a hammer impression in wood; (b) face of hammer used to make the impression.**

If a tool with a broad blade is being studied, a large number of characteristic marks are visible to the unaided eye. A one-to-one size photograph of the mark in evidence and a test mark will suffice. An enlargement of 5X will be satisfactory for an exhibit.

When a small blade such as a razor blade or a pocket knife is used, the width of the impression is narrower and the lines are much finer. In most cases it is extremely difficult to identify a blade from its mark in wood. The structure of the wood is usually too coarse to retain fine markings.



### Shearing Instruments

Scissors, shears, cutting pliers, and similar instruments in which two blades are brought together are frequently deformed by improper use. Scissors, for example, are designed for cutting objects of a particular class such as paper, cloth, or fingernails. When such a scissors is used on a surface for which it was not designed, a slight deformation may be produced. A small nick in one of the blades will produce an irregularity along the line of cutting. The identification of scissors<sup>4, 5</sup> is usually of importance only in document cases where it is desired to identify the sender of a certain letter or paper which bears the marks of cutting. Scissors and shears are quite difficult to identify because of the fact that the two blades pass over each other. Cutting pliers and pincers present a simpler problem, the two edges meeting after they have passed through the material.



**Fig. 74.** A comparison of wire cutter marks: the wire on the left, which was found at the scene, was cut by the same wire cutter used to cut the test piece at the right.

Crimes involving the use of wire are not infrequent. The clipping of telephone wires, sabotage cases, the preparation of a package containing an explosive are a few examples. The wire should always be held in evidence in these cases and examined for the characteristic marks of the wire cutters. If the wire cutters are subsequently found, they should be used to cut a number of pieces of wire similar to the wire held in evidence. A microscopical examination of the ends of the cut wires will reveal a number of characteristic striations. The shape of the lower end of the cut will usually be that of a parabola since the blade cuts the cylindrically shaped wire at an angle with the axis. The outline of this parabola will bear defects which will be further developed as striations toward

the end of the cut. In cutting sample pieces of wire, the cuts should be made at a number of places along the cutting edge since the characteristic marks are different at different parts of the cutter. The examination of the cut wires should be made with a binocular microscope at a magnification of twenty or thirty diameters. If it is found that samples of wire cut by the tool in question are similar in characteristic marks to the wire held in evidence, a low-power photomicrograph (or stereomicrograph) should be made of the two and subsequently enlarged. Figure 74 illustrates such a case.

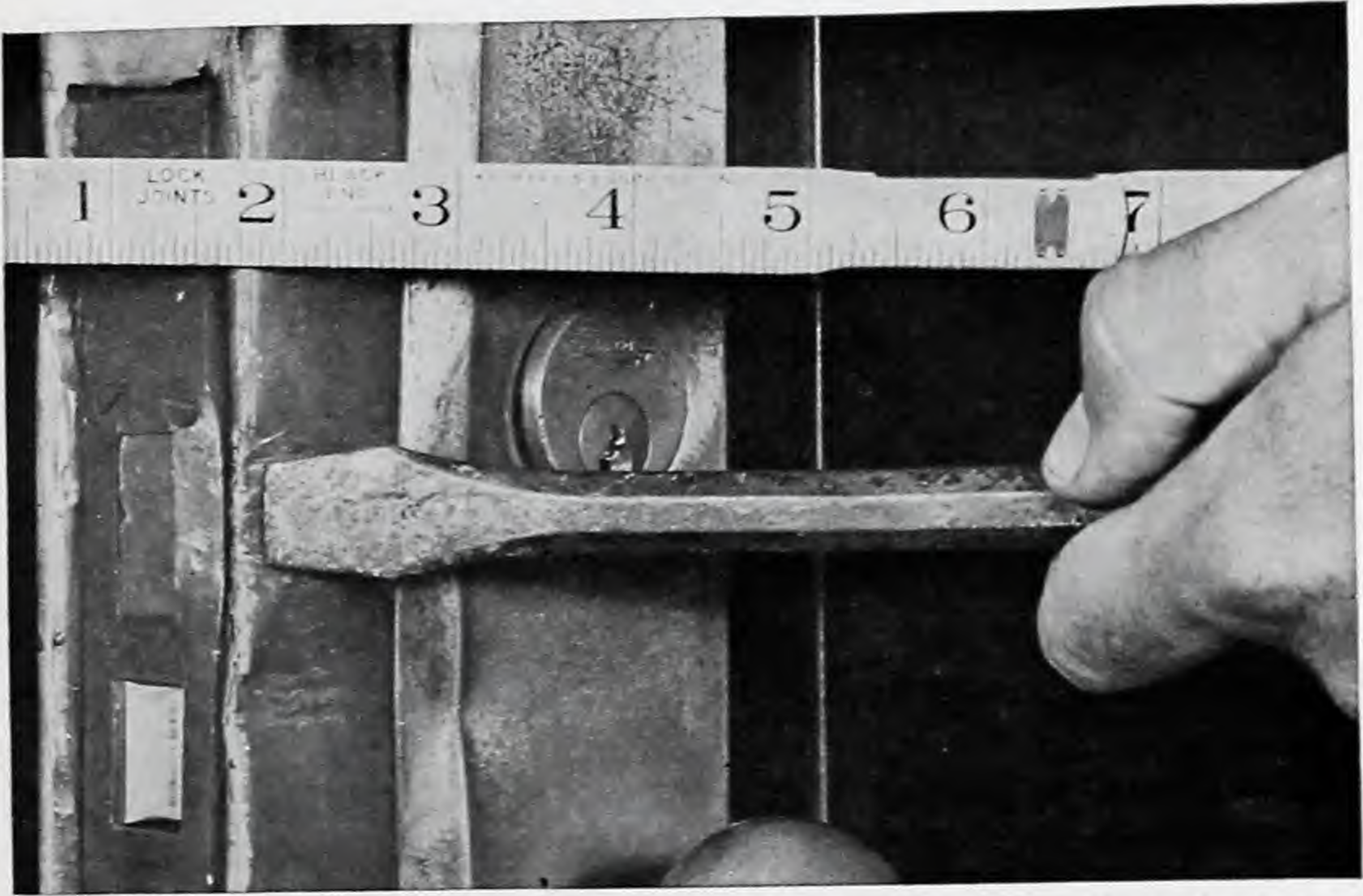
### Levers (Crowbars, Jimmies)

These are the tools most commonly used in the commission of a burglary. The crowbar, jimmy, or screw driver are used to pry open a door or window. The crowbar is used for heavy work such as forcing a heavy door. Since it is



employed in a rough manner and on hard materials, it is unusual to find marks which would characterize the individual tool. Crowbar marks, however, will frequently be apparent. Figure 75 is a photograph of a crowbar mark on a door and the crowbar used to make this mark. Although the measurements of the mark correspond to those of the crowbar, they are sufficient to show only that the mark was made by a crowbar of this type.

The jimmy or screw driver is used to force a window or a drawer; hence it leaves its mark on a wooden or metal surface. This outline of the edge of the tool usually bears characteristic marks because of rough use to which such an instrument is put. Since considerable force is used in making such an impression,



**Fig. 75. A crow bar mark in a door and the crow bar used by the burglar in forcing the door.**

the depth of the mark makes possible a good cast with modeling clay. One photograph should be made with the edge of the tool in the position of the tool mark to show how the mark was made. Another photograph is made to show the edge of the tool slightly displaced from the mark so that the nicks of the edge and the corresponding marks in the impression can be readily seen.

In making test impressions for comparison it will be found that variations of pressure and readjustments of the instrument produce important changes in the resulting marks. A number of experiments will be required before a satisfactory match is obtained. Soft lead is an excellent surface for test marks with tools of this class.



### Pliers

When pliers are used to twist a piece of metal or to loosen a nut, it is possible sometimes to obtain a characteristic impression. Of course, if the pliers are moved or readjusted in the process several impressions will be superimposed and a confusing pattern will result. A similar difficulty is encountered with wrenches: the continuous readjustment of the grip is prohibitive of good impressions. Tryhorn<sup>6</sup> describes a case in which a satisfactory identification was made with spanner marks on valves.

### Files, Saws

A file and saw are sometimes used to cut through bars, hasps of locks, or other metal protective devices in order to commit burglary or larceny. A person

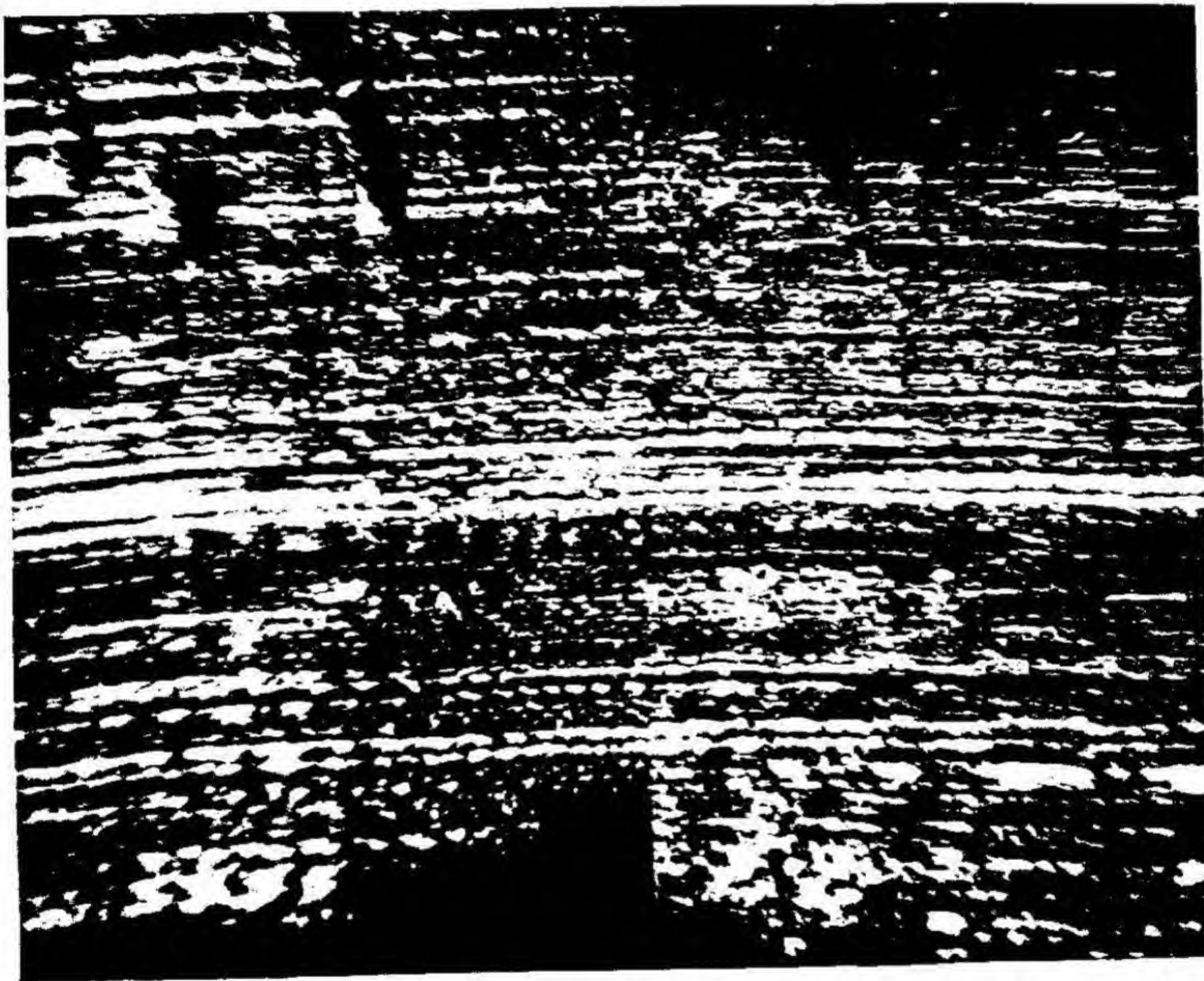


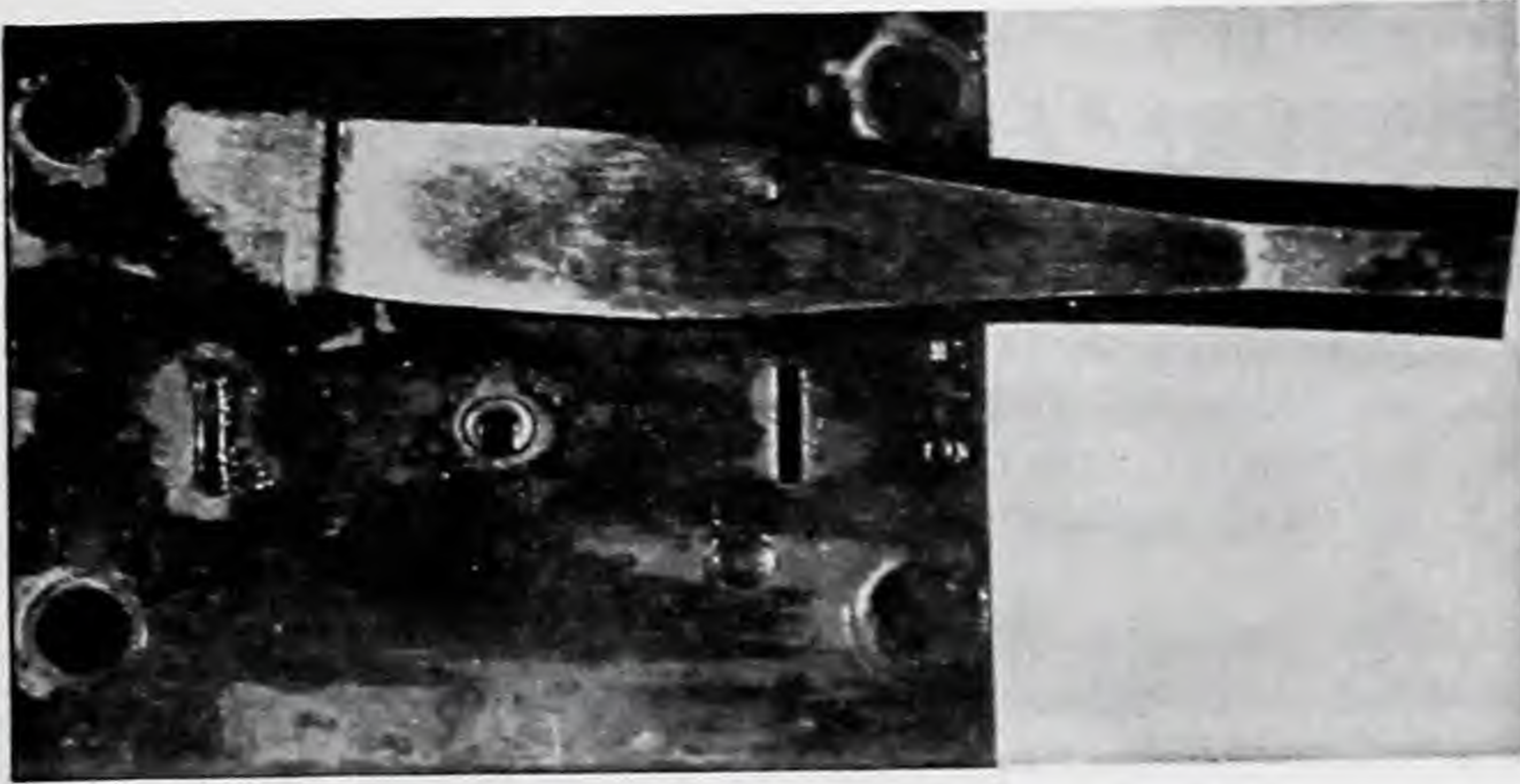
Fig. 76. A comparison photomicrograph of a jimmy impression. On the left is the impression found at the scene; on the right is the test impression made in another piece of metal. (Note the vertical line which divides the illustration in the middle.)

desirous of making a key from a wax or other cast will employ these instruments on a blank key. The comparison of the tool with the markings on metal or wood is usually difficult because of the manner in which it is ordinarily used. The file or saw is seldom applied to an area with a single stroke; usually a number of strokes are made with the result that the characteristic marks of the file are superimposed on the previous impression with each new stroke. In addition, even with the single stroke a considerable length of the file or saw is used. Thus it is difficult to obtain an impression of any part of the tool. Despite these difficulties, however, several cases are recorded of the identification of saws from their marks.



### Miscellaneous

Many other interesting problems in tool identification are to be found in the literature. Among these are the identification of bore and gimlet marks,<sup>7, 8</sup> and of axe marks on trees.<sup>9, 10, 11</sup> An allied subject which may be mentioned



**Fig. 77.** A jimmy and an impression made by it on the rear of a lock in prying it loose. The left hand part of Fig. 76 depicts a portion of this impression under the comparison microscope.

here is the identification of materials from the marks made by the machines in producing them — for example, the identification of wire from die marks<sup>12, 13, 14</sup> or of nails from machine marks.<sup>15</sup>

### EXERCISES

1. Examine the edges and faces of various tools of the types mentioned in the text. Observe any flaws in the surfaces.
2. Using an old hammer which possesses defects on the striking face produce a number of impressions in a wood surface. Strike the surface along a perpendicular to both faces; then strike the surface at an angle. Observe the differences in the impressions. Try to produce an impression with characteristic marks.
3. Using a wood chisel shave off a thin layer of wood. Examine the striations in the mark. Examine the tool for corresponding marks. Make another and similar mark in the wood. Photograph both marks. Direct the lighting obliquely so that good contrast is obtained between the lines and the background.
4. Examine a razor blade under a microscope at a magnification of 60X. Note the irregularities of the edge. Using a pencil or other wood surface shave off a piece of wood and examine the mark for the irregularities which you observed in the blade.
5. Using a wire cutter clip off a number of short pieces from a length of wire. Use the same part of the cutting edges each time. Examine the pieces under the binocular microscope. When two pieces have been found which can be shown to have been cut by the same tool, mount the two pieces and make a photomicrograph at 20 to 30X. (If the camera is available, make a stereomicrograph.)



6. Using a screw driver with a rough edge make a jimmy mark in wood. Examine for characteristic defects. Photograph the edge in the mark and slightly displaced from it. Make a 10X enlargement.

7. With a pair of pliers grip a rusty sheet of tin with considerable force. Bend the sheet without shifting the grip. Examine the tin for marks of the pliers.

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# CHAPTER 11

## MOULAGE AND OTHER CASTING TECHNIQUES

### 1. THE NEED FOR CASTS

A problem of constant occurrence in criminalistics is the faithful representation of objects of evidential value. In many cases reliance can be placed on the photographic method. The ordinary photograph, however, has the limitation of all two-dimensional representations: depth must be estimated from memory and experience. Since spatial relations, in some cases, may be of fundamental importance in establishing proof, the making of models by casting methods is an indispensable technique in the laboratory. Tool marks, tooth impressions, keyholes, and keys, are among the many objects which require a mold for adequate representation. Casts are invaluable also in cases of unidentified dead persons who have not had their fingerprints recorded. Models of scars, broken joints, or other deformities may lead to an identification by a relative in these cases.

A considerable number of casting techniques and formulas are to be found in the literature. Many of these, however, are ill-advised and lacking in scientific basis. The formulas given below have been taken from C. D. Clarke's *Molding and Casting*,<sup>1</sup> a text which should serve as a guide to those interested in work of this nature.

In making models it is usually necessary to make a negative mold of the subject and then to produce a positive cast from the negative. Frequently only the negative is necessary; in a footprint, for example, the cast is a negative of the impression, but it is satisfactory because it represents a positive of the shoe itself which is the object of major interest. In tool impressions the negative represents the form of the tool; the impression itself, however, must be reproduced as evidence, and for this purpose a positive is also made.

The materials most commonly employed for making the negative mold are plaster of Paris or a hydrocolloidal composition which we shall refer to as the *agar mold*. The choice of material is usually dictated by the nature of the subject. The major difference between plaster and the agar molds lies in the elasticity of the latter. If the subject does not possess any undercuts, the plaster may be used; otherwise an agar mold is necessary. In general, the agar mold should be



used for subjects which are complicated in shape. For making positives plaster of Paris or a wax material can be used.

## 2. PLASTER OF PARIS

The elementary technique of plaster casting has already been described for recording foot impressions. Plaster of Paris, however, can be applied to practically all the casting needs of the criminalistician. It is by far the most important of the casting media. The economy of materials and simplicity of equipment and technique recommend its use for all routine work.

In applying plaster of Paris to many surfaces it is necessary to use a separating medium in order to prevent the plaster from adhering to the surface. A thin



Fig. 78. Materials used in moulage work.

application of mineral oil or grease will usually prevent such adhesion. When a mold of a living subject is made, the skin should be rubbed with mineral oil and any hair treated with petrolatum jelly. A soft brush can be used to apply plaster of Paris to objects which possess fine structure so that no detail is lost because of air bubbles.

Plaster of Paris may be used in making either or both the mold (negative) and the cast (positive). Hence we may have a plaster mold and a plaster or wax cast; or we may have an agar mold and a plaster cast. Special techniques must be employed so that the mold will be separable from the cast. The mold can be removed either chemically or by means of a separating medium. To distinguish between mold and cast when plaster has been used for both, bluing



is added to the water in the mold mixture. A simple method of making a plaster mold which is chemically removable is to add one part potato starch to three parts plaster of Paris in making the mixture. When the mold and cast are immersed in boiling water, the mold will fall away from the cast.



**Fig. 79. Moulage cast of a hand. An identifying scar may be seen on the index finger.**

If a separating medium is used the mold can be preserved for further use. To separate a plaster mold from a plaster cast one of the following compositions should be applied to the mold before the cast is made:

Gum mastic	1 part (by weight)
Amyl alcohol	4 parts (by weight)

The gum mastic is dissolved in the alcohol and the mixture is brushed on the mold. The composition should dry for an hour at room temperature before the cast is made.

Yellow beeswax	1 part (by weight)
Carbon tetrachloride	9 parts (by weight)



The wax is permitted to dissolve in the carbon tetrachloride for several days before being used.

When a wax cast is to be made from a plaster mold, the latter is first soaked in warm water and then rubbed or brushed with a soap solution. Excess suds are removed with a brush until a thin soap film remains on the mold. When the cast is made the wax should be only moderately hot.

Another use of plaster of Paris is in the making of positives from plasticine negatives.

Plasticine or modeling clays are used to make the negative of an impression such as a jimmy mark. The plasticine is pressed against the impression so that it is firmly in contact with all the details. It is well to test the plasticine on another part of the surface first; If it sticks to the surface, it should be moistened with water before being used. The plasticine is then removed, placed in a box, and taken to the laboratory where a plaster cast is made. The plaster of Paris and water are mixed in the usual manner in a suitable container. A thin coat of plaster is brushed over the plasticine to prevent air bubbles. The plasticine may be placed on a small platform to which a string is attached and then lowered into the plaster to the necessary depth. When the plaster has hardened, the plasticine may be removed. In doing so, an effort should be made to preserve the form of the plasticine so that it can be used again in the event that the first cast is not a success.

### 3. MOULAGE — AGAR COMPOSITIONS

In casting some subjects it is necessary to make a mold which is somewhat elastic. This is particularly true when the subject possesses undercuts. Agar compositions have been found excellent for this type of work. A mixture of agar and water melts near the boiling point of water and solidifies just above body temperature. On setting, the negative mass is sufficiently pliable to permit the withdrawal of undercut surfaces.

A number of agar compositions for this work are commercially available under such names as *Negocoll*, *Dentocoll*, and *Plastico*. It is not necessary, however, to rely on these relatively expensive commercial compositions, since a number of satisfactory formulas are given in the literature. Clarke,<sup>2</sup> after four years of experimenting, devised the following composition:

Agar (powdered)	4 ounces
Water	100 ounces
Borax or zinc oxide	1 ounce
Oxyquinoline sulfate	10 grains
Glycerin	1 ounce
Cellucotton	$\frac{1}{2}$ ounce
Cotton	15 grains
Rubber cement	4 ounces

Twenty-five ounces of the water are poured into a suitable bottle. The borax, oxyquinoline sulfate, glycerin, cellucotton, and cotton are placed in the bottle



and the whole shaken vigorously until a good mixture is achieved. The agar is mixed in the top of a double boiler with the remainder of the water at room temperature. The mixture is heated and stirred until the agar is completely dissolved. When the solution is at 100 C, the contents of the bottle are slowly added and stirred until the mixture again reaches 100 C. This mass is permitted to cool until it is near the setting point. The rubber cement is then added slowly while stirring. Any bubbling at this point indicates evaporation of the cement solvent.

When the composition has cooled and set, it is ground in a meat chopper and allowed to stand until sufficient water has evaporated so that no drops can be expressed. The substance is stored in an airtight container until needed.

Another excellent agar composition has been described by Gross:<sup>3</sup>

	<i>Parts by weight</i>
Agar	100
Oil soap	100
Magnesium sulfate (bone)	40
Absorbent cellulose waddings	12
Water	700-800

The agar is dissolved, as described above, in two quarts of water. The wadding is macerated in hot water until the fibers are separated and then added to the hot agar mixture. The oil soap is then dissolved in the mixture, and finally the magnesium sulfate is added. The mass is cooled and treated as in Clarke's formula.

Recently developed casting materials which are called *alginates* possess superior qualities and will soon replace agar compounds in practice. The advantage of these materials is that they can be used cold; i.e., it is not necessary to heat them. They possess elastic properties and are especially suitable for use with difficult subjects.

#### 4. MAKING THE MOLD

Since most agar compounds are similar in behavior, a general treatment of the making of a negative mold will suffice. The following equipment is needed: two enameled double boilers for heating the materials, two brushes which are capable of withstanding high temperatures, gauze, plaster of Paris, a thermometer, materials such as wood or bowls for improvising frames, and a meat grinder. The negative material can be used repeatedly if it is not permitted to become mixed with other substances such as the positive material or plaster of Paris. Before and after use it should be ground in a meat grinder. (It should be kept in a covered jar or can when not in use.)

The negative material is placed in a double boiler and heated. If necessary, sufficient water is added so that when the material has melted, a fluid of the consistency of cream is formed. If a cast of a part of a person's body is to be made, the liquid should be cooled to a temperature of about 100 F before being used.



A suitable frame or container is used to hold the object which is being cast, so that the negative material will not run off. Putty or modeling clay can be used to construct walls to prevent this. The material is first brushed on the surface in such a way as to exclude air bubbles. It is then quickly but carefully poured on so that the brushed-on layer does not congeal and form a separate layer. The cast should be at least one-half-inch thick. This thickness can be achieved in two or more layers rapidly applied. A reinforcement may be added in the form of pieces of gauze soaked in plaster of Paris. This backing is necessary wherever one of the dimensions exceeds several inches. In larger casts such as those exceeding twelve inches, pieces of wire may be laid in the cast for reinforcement.

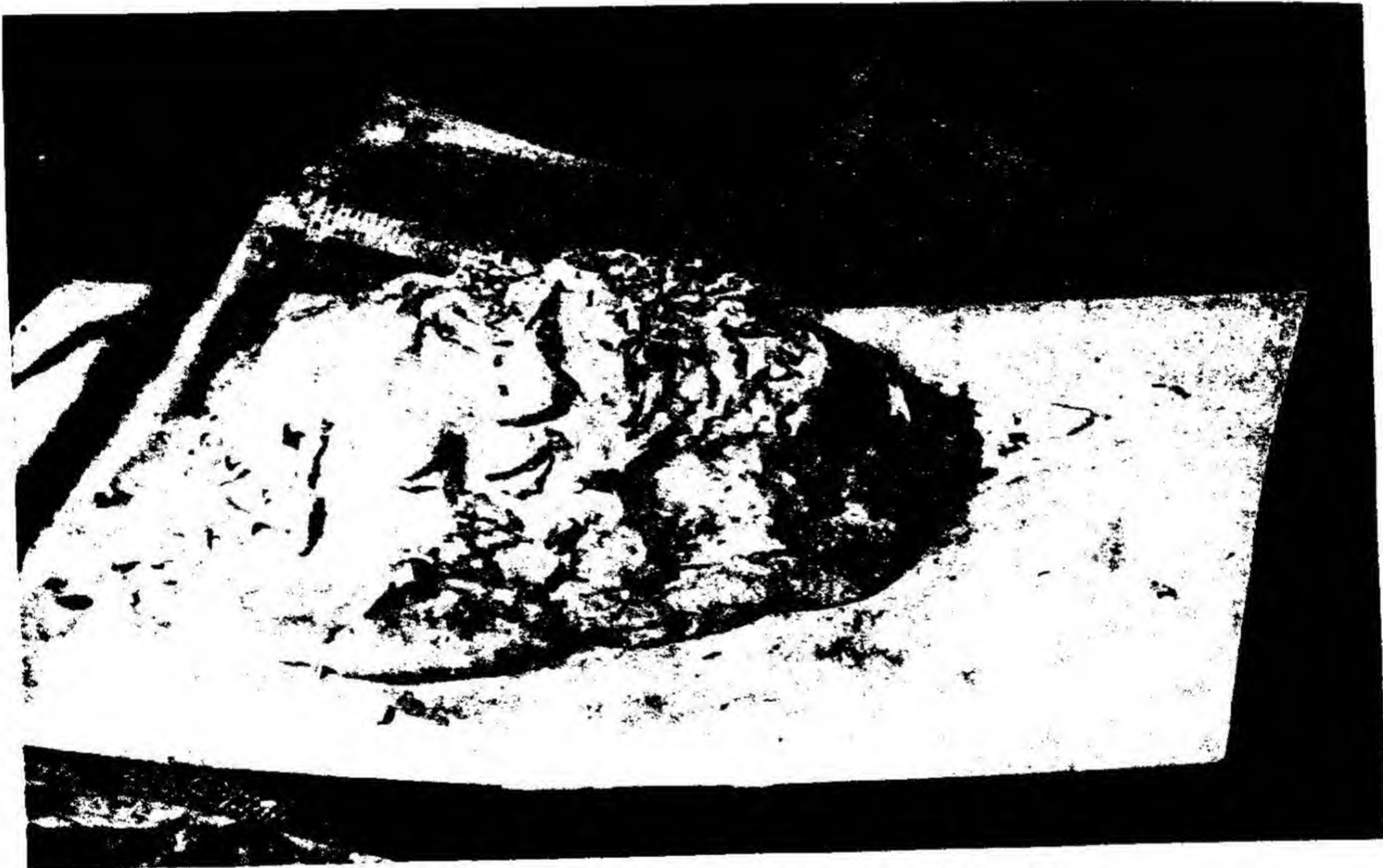


Fig. 80. Making the negative mold of the face.

The negative cast should be permitted to dry for about fifteen minutes or more, depending on the thickness of the cast. After it is carefully removed, it should be placed in a container and suitably supported. Defects such as holes can now be repaired by means of a correction paste. The cast is now ready for the pouring of the positive material.

## 5. POSITIVE MATERIALS

Either plaster or a resin-wax material can be used to make a cast from the agar mold. The use of plaster has already been described. Resin-wax positives are highly esteemed for their lifelike appearance and capacity for reproducing minute detail. Positive substances are available under commercial names such as



*Hominite*, *Celerite*, and *Posmoulage*. Resin is used as the base of most of these formulas. Paraffin is added to give fluidity to the melted material. Wax is used to raise the melting point of the substance. One of the desiderata of a good positive material is that the substance can be brushed into the mold. The qualities of a positive material that can be brushed in are slightly different from those which are suitable for pouring in.

Clarke<sup>4\*</sup> gives the following formula for a positive material which can be brushed in:

	Parts by weight
'Parawax' (paraffin 56 C)	5
Rosin (colophony, bleached)	8
Light carnauba wax	1
Talc	2
Zinc oxide	$\frac{1}{4}$
(Color to suit hue of subject)	

The paraffin and wax are melted together in the top of a double boiler. The rosin, talc, and zinc oxide are successively stirred into the mixture. When the material solidifies and cools, it can be broken up and stored.

The following formula is given by Clarke<sup>5\*</sup> for a positive material which can be poured into the mold:

'Parawax' or paraffin	8 ounces
Carnauba wax (light)	2 ounces
Beeswax (yellow)	1 ounce
Rosin (w.w. bleached)	2 ounces
Turpentine or benzene	$1\frac{1}{2}$ drams

The turpentine or benzene is added after the mixture has been removed from the flame.

The positive material can be colored for various purposes. The colors may be chosen for esthetic or practical value. For a cast of a hand, a flesh color may be selected; for a tool mark, a brown or other color which will give the contrast desired for an examination. The finished cast of the positive material is of a hard, waxy appearance. Like the negative material, this substance can be reheated and used over again if it is free of impurities.

The preparation and application of the positive material is similar to that of the negative. The pieces are melted in a double boiler until a thin liquid without bubbles is obtained. A thin layer is spread on the negative with a special brush. The material is then poured to a thickness of about an eighth of an inch. Hardening takes place very rapidly. Gauze sections are then placed over the cast and soaked with another layer of the positive material. This process is repeated several times.

\* From *Molding and Casting*, by C. D. Clarke, copyrighted 1938, by C. D. Clarke.



Fig. 81. A cast of the face.



If it is desired to make a moulage cast at the scene of the crime, a portable outfit can be easily arranged. The negative material should be first melted in the laboratory and then placed in a large vacuum bottle. An enamel pot can be used for heating the positive material if care is exercised to avoid burning.

## 6. METALS SUITABLE FOR CASTING

### Aluminum

For impressions on hard surfaces, such as crowbar marks in a metal door, a thin sheet of aluminum can be used. The sheet is fitted into the impression with a small stick which is carefully pressed against all parts of the surface. The aluminum sheet may be strengthened by applying a backing of plaster of Paris.

### Wood's Metal

This is a metal of low-melting point (71 C) which is suitable for casting tool marks. Its composition in parts by weight is:

Bismuth	50.0
Lead	25.0
Tin	12.5
Cadmium	12.5

## 7. MOULAGE METHODS FOR VARIOUS IMPRESSIONS

### Tool Impressions

If the tool impression is in wood or other porous substance, a solution of benzol and paraffin should first be brushed on. When the benzol evaporates, a thin coat of paraffin remains to protect the negative material from the wood. This precaution must be taken because porous materials draw the water out of the negative material causing it to lose its elasticity and to adhere to the surface. Some porous materials can be prepared by soaking them with water.

### Gun Barrels

Problems in firearms identification sometimes require a cast of the gun barrel. This can be easily accomplished by first pulling an oily rag through the barrel, blocking one end with a plug, and then pouring in the positive material.

### Casts of Parts of the Human Body

It is sometimes required to make a cast of a human hand or face. It is important that the temperature of the negative material should be below 110 F. A temperature greater than this will be uncomfortable if not injurious. Casts of the face require some experience. The material is not harmful to the face, but the eyes should, of course, be closed. Considerable reinforcing is needed for such a large cast. Special frames are available for this type of work. Casts of the faces of dead persons are sometimes made for identification purposes. Naturally, where a corpse is concerned, less consideration is required in regard to the temperature, although the state of decomposition of the body should guide the operator in all cases.



**EXERCISES**

1. Prepare a deep tool impression in a metal or wooden surface by means of a screw driver the edge of which has first been nicked in order to give a characteristic mark. Photograph the impression with a scale in the field.
2. Using placticine or modeling clay and plaster of Paris make a cast of the impression.
3. Make another cast using a very thin sheet of aluminum. Strengthen the aluminum with a backing of plaster of Paris.
4. Make a moulage cast of the impression. Use putty or modeling clay to surround the impression in order to contain the negative material.
5. Compare the three casts for fine detail. Which gives the best reproduction?
6. Make a cast of a gun barrel. What difficulties are encountered?

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# PART D

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## PHOTOGRAPHY AND THE CRIME LABORATORY

In scientific crime detection, the camera assumes a place of paramount importance among laboratory instruments. All the resources of photographic science must be at the disposal of the police scientist. The four major functions of photography in the laboratory are to provide: (1) a record of the initial appearance of evidence; (2) a record of the scene of a crime or some aspect of a crime which can not be preserved in its present state; (3) a means of illustrating points of evidence in court; (4) a method of making visible various aspects or details of evidence that cannot be seen by the human eye. These functions of photography are discussed below in greater detail.

### 1. THE PHOTOGRAPHIC RECORD

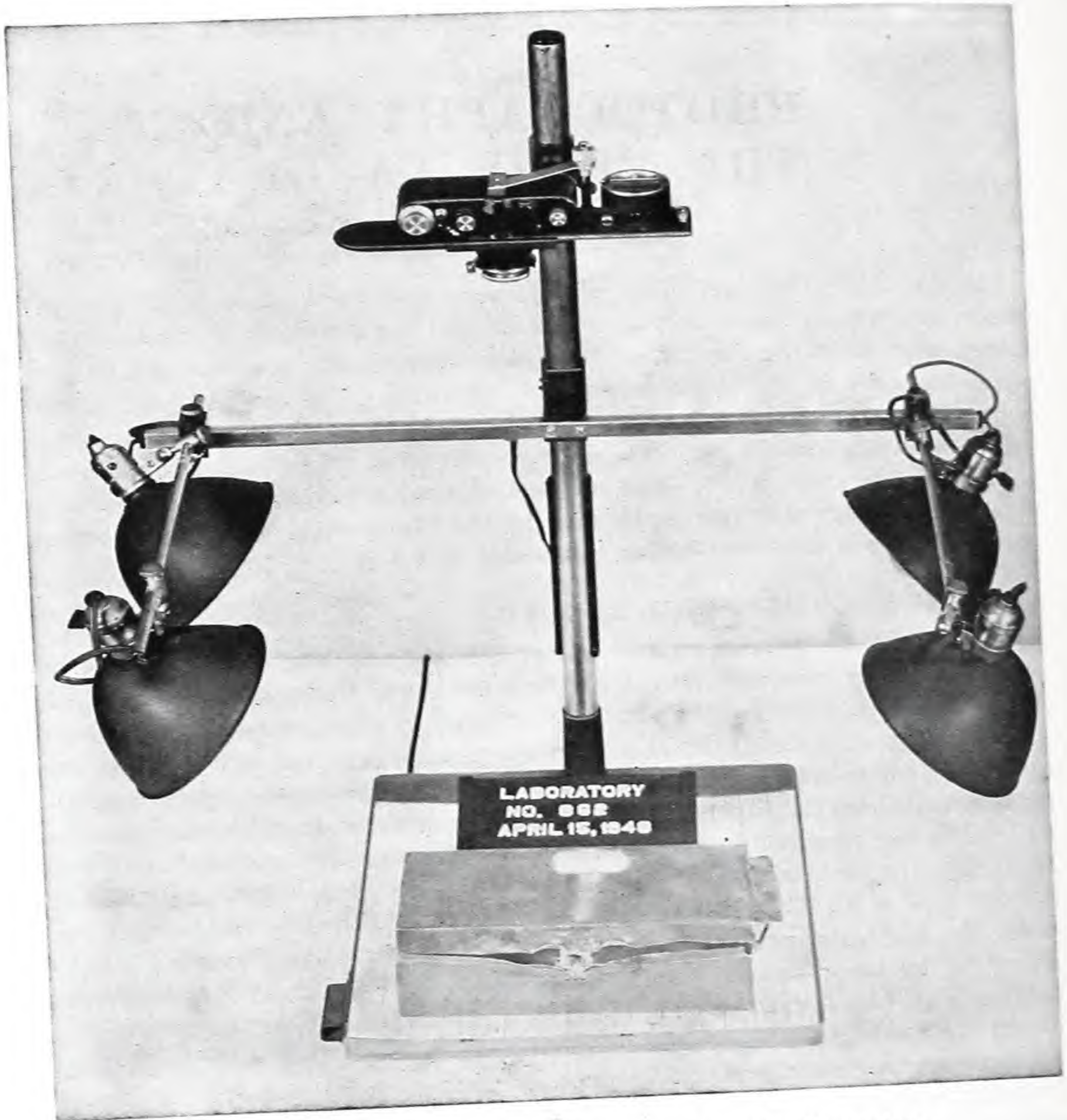
It should be a general rule in the police laboratory that all evidence be photographed as soon as it arrives at the laboratory. Very often in the course of an examination, the evidence must be treated in some manner which alters its original appearance. If the procedure in question is a chemical analysis, the quantity of the substance will be diminished. If the evidence is an altered document, treatment of the paper will necessarily change some details. Consequently, for legal as well as scientific purposes, it is desirable that a record of the original appearance be retained. A 35 mm camera of the Leica, Contax, or Kodak Bantam type is ideal for this purpose because of its economy and simplicity. Color film and color prints should be used if possible. When evidence is submitted to the laboratory, it should be placed on the stand with appropriate lighting (Fig. 82). A card bearing the laboratory serial number should then be placed at the side of the object and the photograph taken. A separate file of these photographs, together with such photographic data as position of lights, *f*/number, exposure, etc., should be maintained. A copy should also be placed with the folder containing the case data and report.

### 2. AT THE SCENE

It is not to be expected that the scene of a crime will be left undisturbed for an indefinite time. At a motor vehicle homicide, for example, traffic cannot



be detoured for long. Nevertheless, a record of the position and condition of the details of the scene must be made before they are altered in any way. Footprints and tire marks must be photographed before casts are made. In the case



**Fig. 82. Photographing evidence received at the laboratory.**

of a homicide indoors, the spatial relations of body, walls, ceiling, and furniture are important. In these and many other situations, unless a photographic record is made, vital evidence may be lost.



### 3. COURT DEMONSTRATIONS

"One picture is worth a thousand words." The truth of this proverb will be evident to the expert witness who must explain his case findings to a court. Ordinarily the judge and the members of the jury are persons of limited scientific background. The expert witness is an expert precisely because he is in possession of a body of knowledge not ordinarily available to the average layman. His success as a witness depends upon his ability to translate the language of his science into familiar terms and to meet the layman on his own ground. This is most expeditiously done with the aid of photographs and line drawings. Pictures and simple diagrams should be used. The nature of many classes of cases is such that a comparison by photographs brings out clearly the desired points. For example, handwriting cases are most clearly demonstrated by means of enlargements of photographs of the true and disputed writings; fingerprint comparisons are best shown with greatly enlarged photos mounted side by side, the characteristics being indicated by numbered arrows; the correspondence of tire marks on pavements with the tire itself can be shown photographically. Many other possibilities, too numerous to mention, will suggest themselves to the investigator.

### 4. PHOTOGRAPHIC LABORATORY METHODS

The human eye is sensitive to only a small portion of the electric wave spectrum. The infra-red and ultraviolet regions which border the visible part of the spectrum cannot be detected by the eye, but their radiations can affect certain photographic emulsions. This property of infra-red and ultraviolet radiations suggests their use in photographing objects for the purpose of introducing a contrast not apparent to the eye. For example, where ink lines have been superimposed on other writing, it is sometimes possible by photographing the document with infra-red film and an appropriate filter to render this writing legible. By photographing in ultraviolet light fraudulent tickets can sometimes be distinguished from genuine ones by the difference in the appearances of their fluorescence.

If certain characteristics of evidence are such that they are too small to be seen by the human eye, photography again proves an invaluable ally in the form of photomicrography. Hair and fiber analyses should be supplemented by photomicrographs. Hidden defects of metals, correspondence between two sections of a broken object, tool marks, and many other subjects can be more satisfactorily studied in this manner.

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In the following treatment an effort has been made to stress the scientific aspect of photography. The camera is treated as an optical instrument the operation of which is governed by definite physical laws. The language of the professional photographer has been to some extent avoided in favor of the terminology of physics. It is essential that the police scientist have a thorough



knowledge of the simple optical laws that are explained in the following chapters. An astute defense counsel will often call into question the validity of a photograph as evidence because of the distortions that may be introduced by unintelligent manipulation of the camera. This line of inquiry may lead to an interrogation of the photographer to establish his competence. Questions such as the following can be asked:

What does the term  $f$ /number mean?

How are focal length and plate diagonal related?

What are the ordinary precautions to take in order to maintain "true" perspective?

What is the relation between bellows extension and the distance of the camera from the object?

Upon what factors does depth of field depend?

Explain the following terms: *latitude*, *density*, *contrast*, and *gamma*.

If a black fingerprint is found on a red background, what film should be used in photographing it?

These questions are by no means a fair test of a photographer's ability. The average professional photographer may not be able to answer them satisfactorily, even though he is in possession of the practical knowledge which the answers are intended to imply and uses this knowledge constantly. The jury, however, must judge the expert witness on the basis of his qualifications and his responses to questions such as these. Herein lies the difference between the expert photographer and the expert witness in photography. The latter, although perhaps less technically capable than the former, is prepared to explain the terms and procedures of photography in the language of elementary science.

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# CHAPTER 12

## PHOTOGRAPHIC OPTICS

### OBJECT AND IMAGE RELATIONS

For practical purposes it is possible to use a camera successfully without any knowledge of the optical laws governing the formation of images. Since our purpose, however, is not restricted to the merely practical, and since an elementary knowledge of the theory will in many situations reward the possessor by a saving of time and unnecessary manipulation, the reader is advised to refresh his memory on these matters by consulting the chapters on optics in any standard textbook of physics. In the present section a number of equations will be given which will be found useful in determining the relationships among object distance, bellows extension, object size, image size, and focal length.

#### 1. OBJECT DISTANCE AND IMAGE DISTANCE

If  $p$  = object distance (lens to object),  $q$  = image distance (bellows extension), and  $F$  = focal length, we have

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{F}. \quad (1)$$

This equation is true for thin lenses. For thick lenses (and good lenses are thick lenses) a more elaborate equation is needed. Since the photographer's interest in these equations is concerned mainly with their use in approximating bellows extension and object distance, the thin lens equations will be found satisfactory. From equation (1) we have also

$$p = \frac{qF}{q - F} \quad \text{and} \quad q = \frac{pF}{p - F}. \quad (2)$$

If we write equation (1) in the form

$$0 = pq - Fq - pF, \quad (3)$$

add  $F^2$  to both sides, and factor, we have the Newtonian form

$$F^2 = (p - F)(q - F). \quad (4)$$



## 2. MAGNIFICATION, FOCAL LENGTH, OBJECT DISTANCE AND IMAGE DISTANCE

The magnification (lateral) is defined as the ratio of height of the image to the height of the object. If  $m$  = magnification;  $O$  = height of object; and  $I$  = height of image; we have

$$m = \frac{I}{O} \quad (5)$$

By similar triangles

$$\frac{I}{O} = \frac{q}{p}; \quad (6)$$

hence

$$m = \frac{q}{p} \quad (7)$$

Using equation (2), we have

$$m = \frac{F}{p - F} \quad \text{and} \quad m = \frac{q - F}{F} \quad (8)$$

Rearranging these we have

$$F = \frac{pm}{1 + m} \quad \text{and} \quad F = \frac{q}{1 + m}; \quad (9)$$

also

$$p = F \frac{(1 + m)}{m} \quad \text{and} \quad q = F(1 + m). \quad (10)$$

Examining equation (8),  $m = \frac{F}{p - F}$ , we see that if  $2F > p > F$ , then  $m > 1$ . In other words, when the object distance is less than twice the focal length

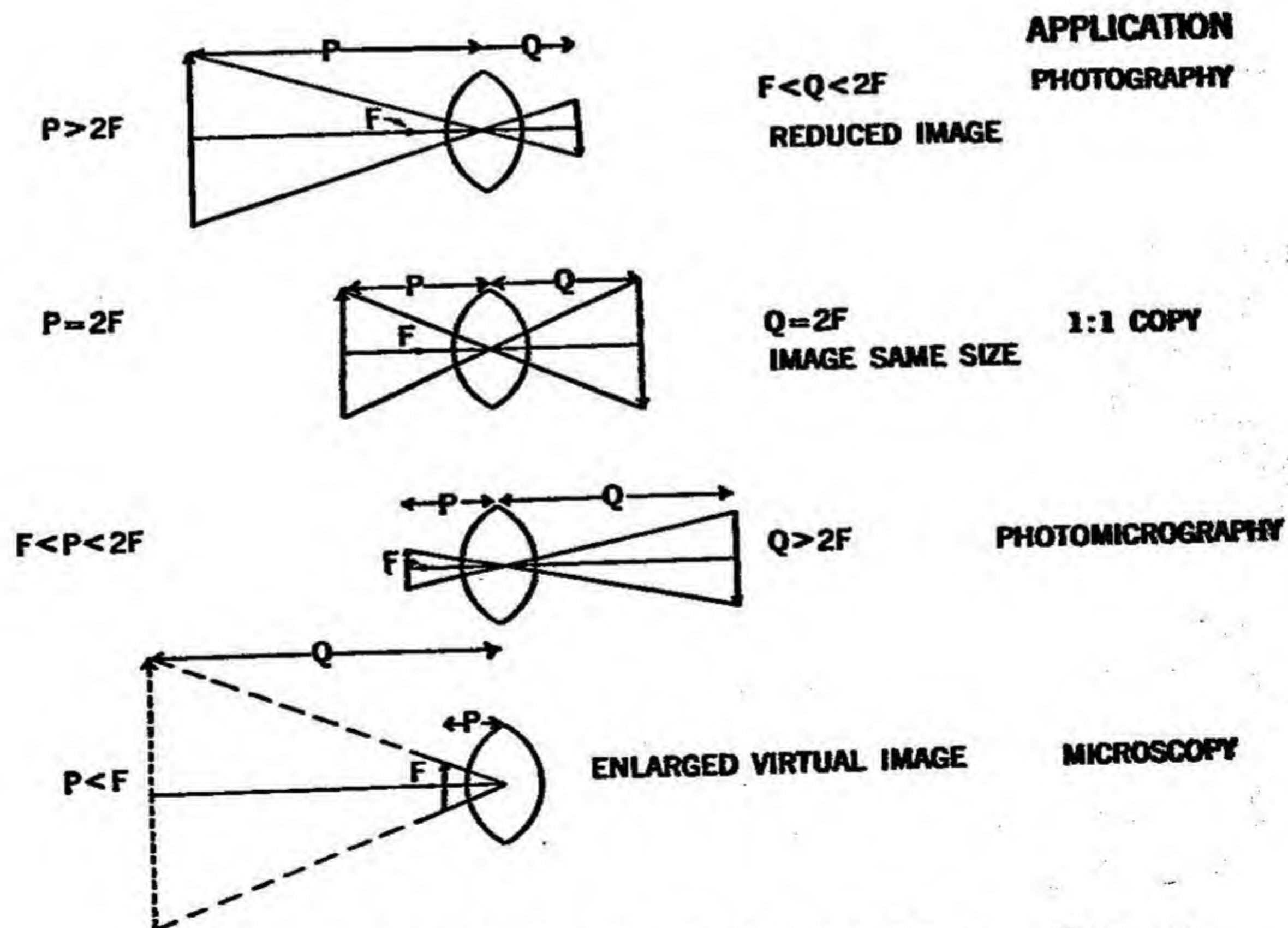


Fig. 83. The relation between object and image distance.



length, but greater than the focal length, the image will be larger than the object. Where  $p > 2F$ , we have  $m < 1$ ; i.e., the image is smaller than the object, which now lies at a distance greater than twice the focal length from the camera. If  $p < F$ ,  $m$  is negative, the image is virtual and is not seen on the groundglass. For  $p = 2F$ ,  $m = 1$ , and  $q = 2F$ ; i.e., for a one-to-one size photograph such as the photograph from a fingerprint camera, the object and plate are each at a distance of  $2F$  from the lens. When  $p = F$ ,  $m$  is not defined; the image is said to be at infinity. Figure 83 illustrates the various cases.

**EXAMPLE 1.** An 8 by 10 camera with a lens of 12 inches focal length is being used to photograph a rifled safe, 10 feet in height. How far away must the camera be placed in order just to fill the plate, i.e., to fit the 10-foot dimension of the object along the 10-inch dimension of the negative?

Since  $I = 10 \text{ in.} = \frac{10}{12} \text{ ft.}$ , and  $O = 10 \text{ ft.}$ ,

by substituting in  $m = \frac{I}{O}$

we have  $m = \frac{10}{10 \times 12} = \frac{1}{12}$ .

Applying equation (10),

$$p = F \left( \frac{1}{m} + 1 \right) = 12 \left( \frac{1}{\frac{1}{12}} + 1 \right),$$

or

$$p = 15 \text{ ft.}$$

**EXAMPLE 2.** In taking a photomicrograph with a 32 mm lens, it is desired to achieve a magnification of 20X. What is the approximate extension of the bellows? Again using equation 10 and substituting  $F = 3.2 \text{ cm}$  and  $m = 20$ , we have

$$q = F(1 + m) = 3.2 \times 21$$

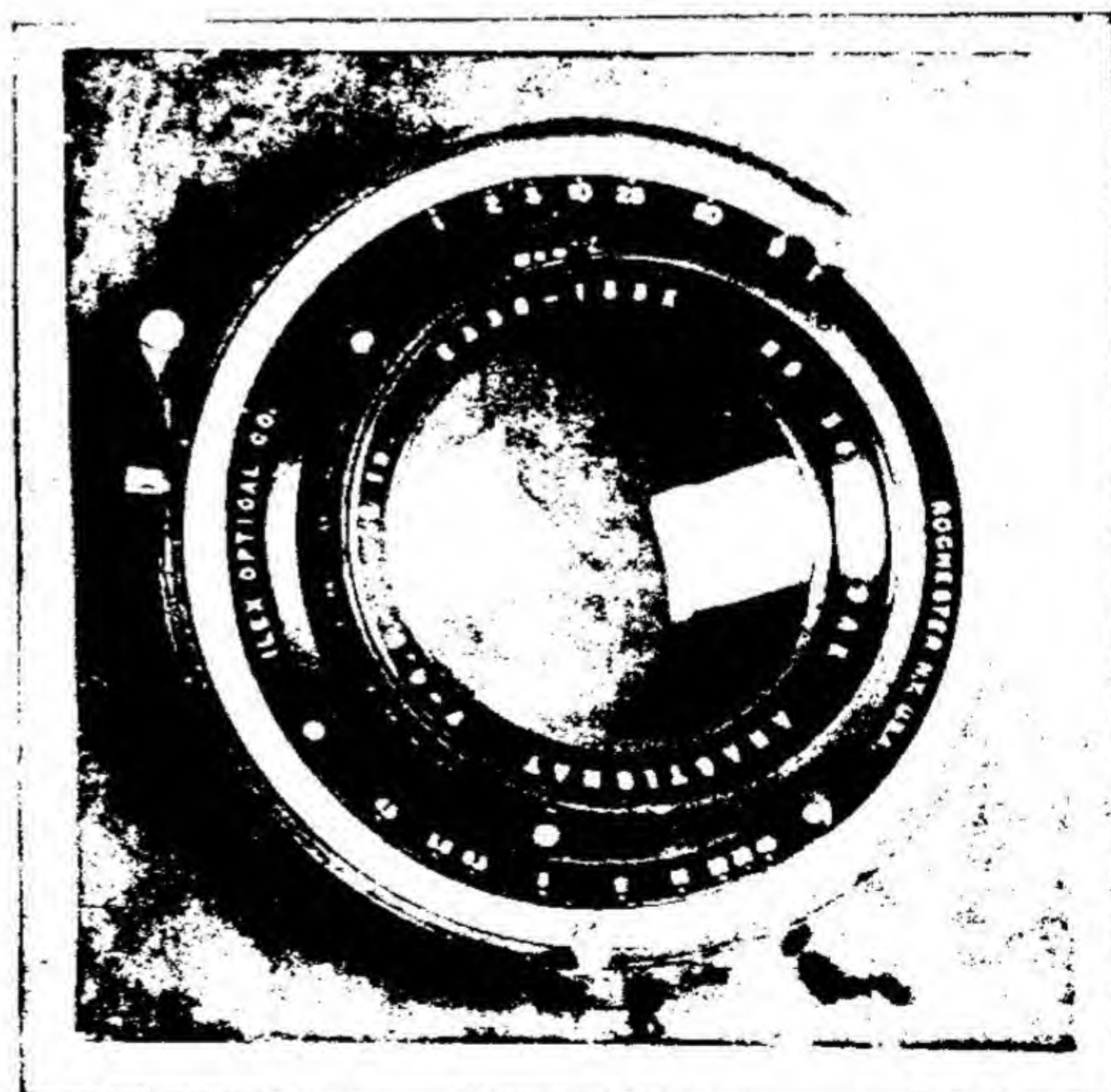
or

$$q = 67 \text{ cm.}$$

## THE ANGLE AND SPEED OF LENSES

### 3. LENS DATA

If a photographic lens and its auxiliary mechanism (shutter) are examined, it will be found that certain information is inscribed on the lens mount (Fig. 84). First, the focal length of the lens is given; second, a series of  $f$  numbers are found associated with a device for adjusting the diameter of the diaphragm; third, a series of numbers indicating exposure times will be found. The meaning



**Fig. 84.** A lens and its mount. The focal length is inscribed on the inner rim; exposure times are on the upper part of the outer rim;  $f$  numbers are on the lower part of the outer rim.



of these last numbers is obvious; the significance of the first two terms is discussed in the present section. It will be found that a knowledge of the use of

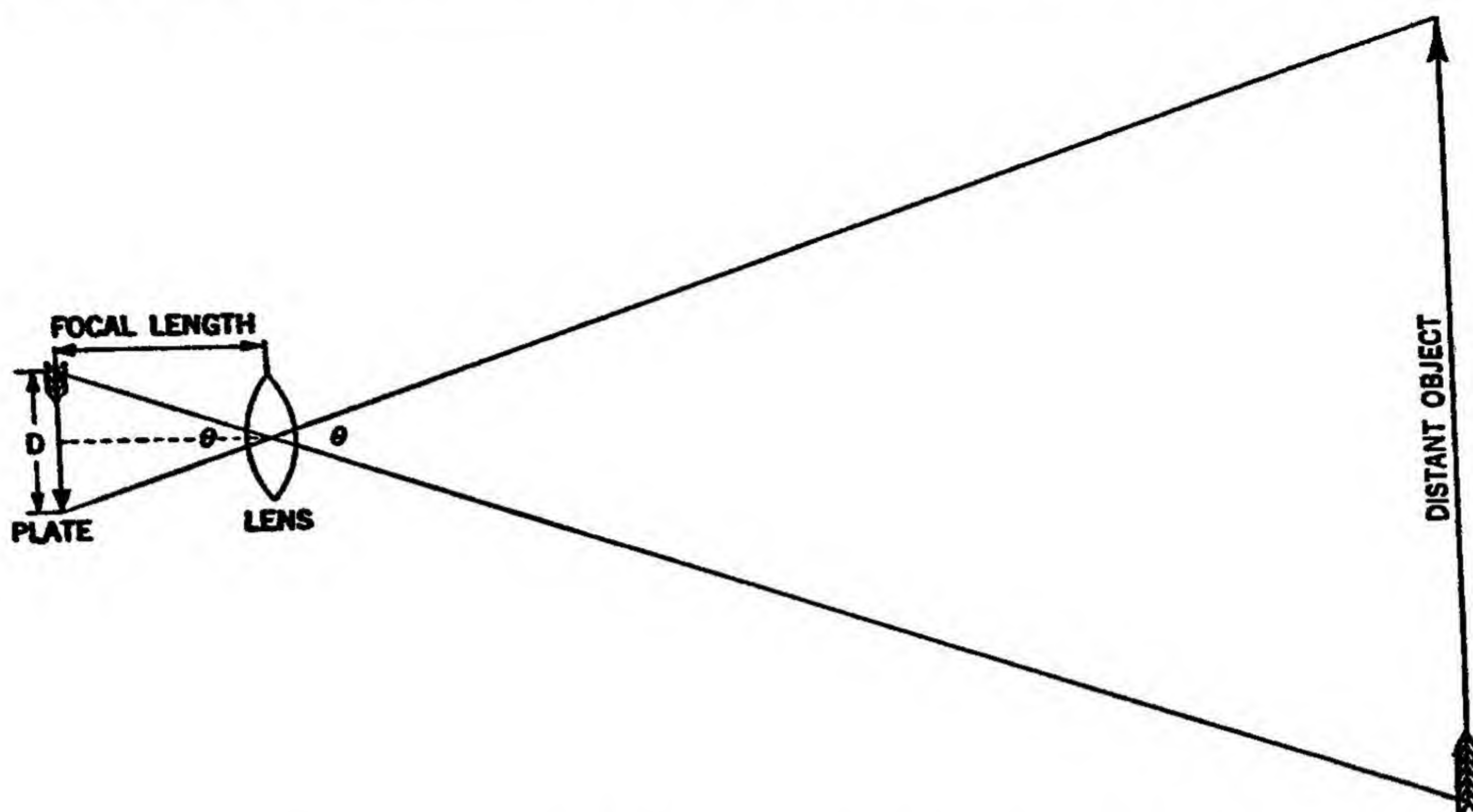


Fig. 85. Illustrating the relation between focal length and plate diagonal.

these two factors — focal length and  $f/\text{number}$  — will be helpful in understanding the physics of image size, exposure, and depth of field in photography. The focal length of a lens, as we shall see, determines the angle of view and the image size;  $f/\text{number}$  controls exposure and depth of field.

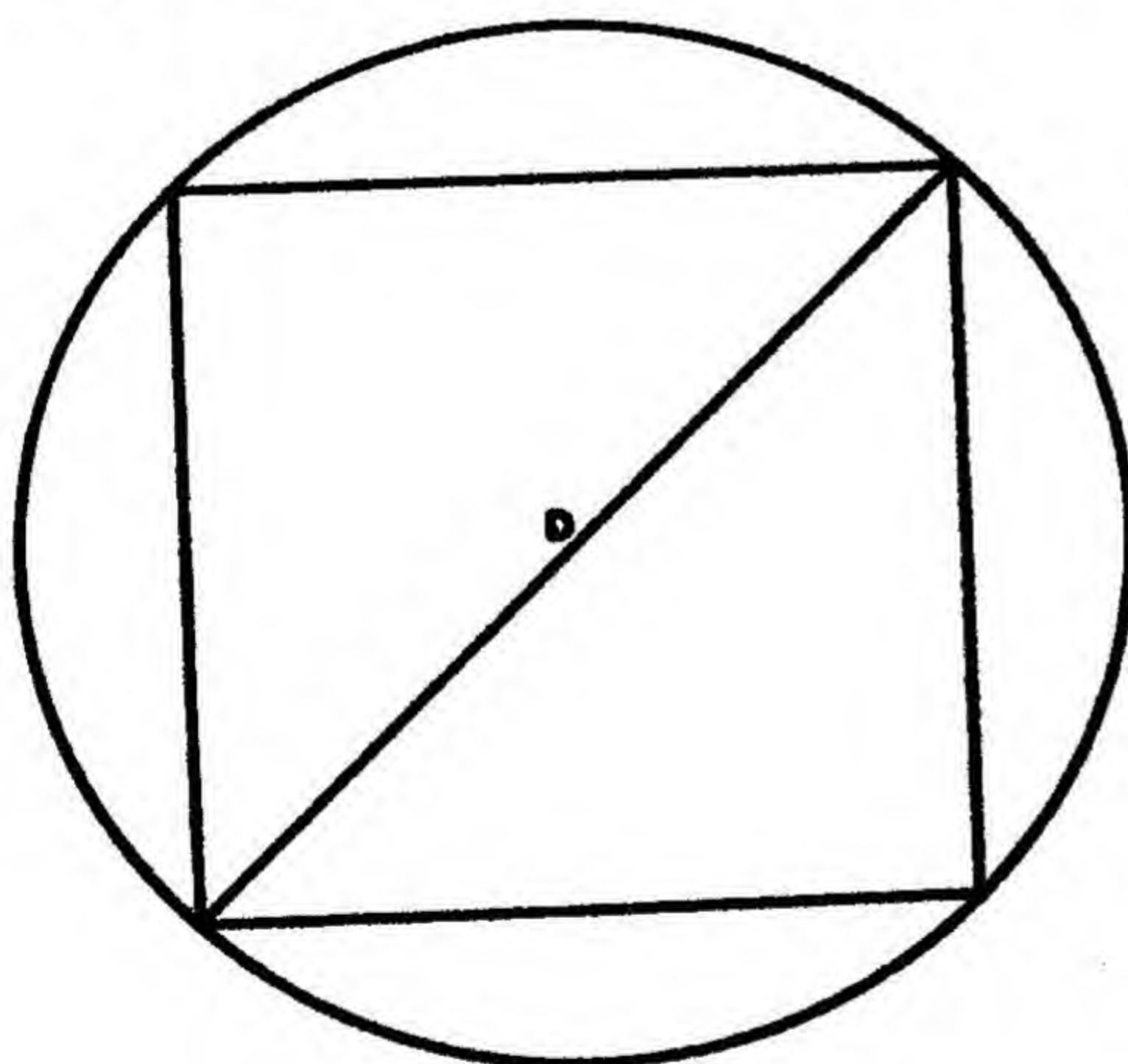


Fig. 86.

#### 4. ANGLE OF VIEW

The angle of the visual field covered by the eye with good definition and no distortion is approximately 50 degrees. The angle subtended by a camera lens should be approximately of the same value in order to simulate the same perspective. The plate of the camera also must be limited in size so that the finished print will subtend an angle of 50 degrees when viewed by the eye at a distance equal to the focal length of the camera (or other distance on enlarging). In Fig. 85 we have the lens of focal length  $F$  subtending an angle  $\theta$  at

the object and at the plate. What must be the value of  $D$  the diagonal of the plate, if  $\theta$  is to be approximately 50 degrees? (Angle  $\theta$  is in reality a solid angle



intercepting the plate in a circle. We may think of the plate as a rectangle inscribed in this circle [Fig. 86], and the diagonal of this rectangle as being a measure of the diameter). From Fig. 85 we have

$$\frac{D}{2} = F \tan \frac{\theta}{2} = F \tan 25^\circ$$

and

$$D = 0.93F$$

That is, the diagonal of the plate should be approximately equal to the focal length of the lens. Such a lens is called a *medium-angle* lens. The following divi-

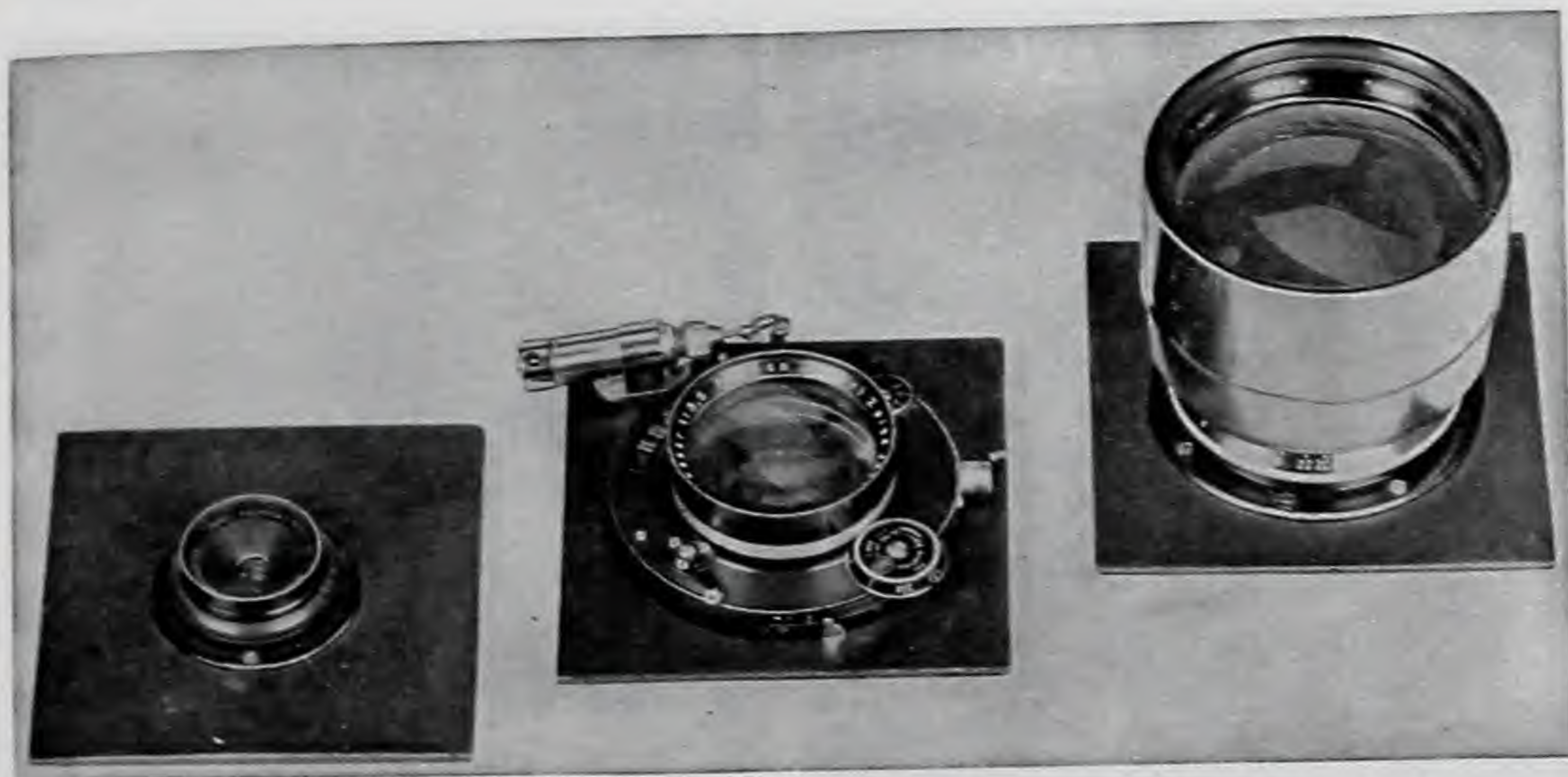


Fig. 87. Wide-angle, normal angle, and telephoto lenses for the 4 X 5 camera.

sion of lenses (Fig. 87) according to angle can be made: medium-angle,  $45^\circ$  to  $75^\circ$ ; wide-angle, greater than  $75^\circ$ ; small-angle (or telephoto), less than  $45^\circ$ . The angle of view varies inversely as the focal length, as we shall see.

## 5. WIDE-ANGLE LENS

When a homicide occurs in a house, it is necessary to photograph the interior of a room. Since the camera must usually be set up in the room, it is found that only a small section of the opposite wall can be seen on the ground-glass. In order to include a larger area of the wall on the plate, we must make the relative image size smaller; i.e., reduce the magnification. From equation (8) we have

$$m = \frac{F}{p - F} \quad (11)$$

To reduce the magnification  $m$ , we must either increase the object distance  $p$  (i.e., set the camera farther back), or else decrease  $F$  the focal length of the lens which is used. Since we are confined to the room,  $p$  is constant; hence we must use a lens of smaller focal length to include on the photographic plate a field



of satisfactory extent. Such a short focus lens is called a *wide-angle lens*. The focal length is short in comparison with the diagonal of the plate. Corrections are usually made for this larger angle at the expense of relative aperture.

## 6. TELEPHOTO LENS

The opposite problem will confront the photographer when he attempts to photograph an inaccessible distant object so as to obtain a relatively large image on the plate. For example, if a bullet is fired through a window of one building and enters the window of another at a considerable distance, a photo-



(a)



(b)

Fig. 88. A scene of a crime photographed with (a) a wide angle lens; (b) a telephoto lens. Notice that in both pictures the width of the foot of the bed is the same. Holding (a)  $3\frac{1}{2}$  in. from the eyes will correct the perspective. For (b) the viewing distance should be 13 in. If (b) is held close to the eyes there is an apparent foreshortening of the legs.

graph of the second window taken from the first will be unsatisfactory because of smallness of the image. In this case we must increase the magnification. The object distance  $p$  is fixed; hence the only way in which to increase  $m$  is to make  $F$  larger. Therefore we must use a lens of long focal length. This type of lens is called a *telephoto lens* when the rear focal point is situated in front of the lens.

## 7. PHOTOGRAPHING IN SECTIONS

Before leaving the previous problem of photographing the interior of a room, reference should be made to an alternative procedure which may be followed where the photographer is not in possession of a wide-angle lens. The interior of the room can then be photographed in sections. A satisfactory viewpoint is first selected and the tripod set up. The camera is then arranged on the tripod with the lens directly over the tripod screw. After each exposure, the camera



is turned so that the prints may be joined to give a complete view. In doing this, an object is noted on the end of the groundglass for use as a reference mark. The camera is then turned so that this object now appears on the other side of the groundglass. This procedure insures continuity in the series of images.

## 8. THE SPEED OF A LENS AND THE $f$ /SYSTEM

Exposure,  $E$ , may be defined as the product

$$E = it, \quad (12)$$

where  $i$  is the intensity of illumination and  $t$  is the time during which the light acts on the plate. For a given type of film and fixed conditions of illumination, the length of exposure time is a function of the focal length of the lens and its effective aperture. For the purposes of this discussion, effective aperture may be considered as the diameter of the element limiting the entrance of light. (See Chap. 38 for a definition of *effective aperture*.) When the lens is used wide open, the effective aperture is usually the diameter of the lens. At other times the effective aperture will be considered the diameter of the diaphragm opening. The relation between the focal length and the effective aperture which will be developed here is called the *relative aperture* or "speed" of the lens.

If the illumination of the object remains the same, then the larger the area of the image, the less the light intensity per unit surface area (for corresponding areas), and the longer the exposure time. However, from equation (11) it is evident that the linear size of the image depends on the focal length of the lens. This may be seen also by considering the focusing operation. In enlarging the image on the focusing screen, the bellows extension must be increased. By the inverse square law, the light intensity falls off inversely as the square of the distance of the plate from the lens. The linear size of the image, then, is proportional to  $F$ , the focal length. Hence the area of the image is proportional to  $F^2$ . Exposure time increases with the area of the image. Therefore, exposure time is proportional to  $F^2$ .

The "quantity" of light entering the camera varies as the area of the effective aperture. The area of the effective aperture is equal to  $\frac{\pi d^2}{4}$ , where  $d$  is the diameter of the effective aperture. Hence, the time of the exposure decreases as  $d^2$  increases.

We can write these conclusions as follows:

$$t = k \left( \frac{F}{d} \right)^2 \quad (13)$$

where  $k$  is a proportionality constant the value of which depends upon the type of the film used, the illumination, and the object photographed (among other things).

The expression  $\frac{F}{d}$  is called the *relative aperture* or "speed" of the lens and is referred to as the *f/number*. Thus a lens marked  $f/4.5$  possesses a focal length



and diameter of effective aperture which have a ratio of 4.5. For example, a lens of 50 mm focal length with a maximum effective aperture of 9 mm has an  $f$ /number of 5.6. The  $f$ /number marked on the lens indicates the greatest relative aperture of the lens; the lower the  $f$ /number, the faster the lens. An  $f/3.5$  lens, for example, is faster than an  $f/4.5$ . Better corrections are required in order to make the lens effective at  $f/3.5$ .

## 9. THE $F$ /SYSTEM

The diaphragm or stop numbers on the lens mount usually are  $f/4.5$ ,  $f/5.6$ ,  $f/8$ , etc. These numbers are chosen so that their squares form a geometric progression in which successive numbers differ by a factor of two. The reason for this is obvious when we consider that the exposure time is proportional to the square of the  $f$ /number; thus from equation (13) we have

$$t = k(f/)^2 \quad (14)$$

If now we have an exposure time of  $t_1$  for  $f/11.3$ , and an exposure time of  $t_2$  for  $f/8$ , these exposures are related by

$$\frac{t_1}{t_2} = \frac{(11.3)^2}{(8)^2} = 2$$

or

$$t_1 = 2t_2$$

In other words, in the  $f$ /system each exposure is twice that of the preceding one. For practical purposes strict adherence to this rule is not maintained. The following table of  $f$ /numbers is given together with the relative exposure.

$f$ /number	$f/3.5$	$f/4.5$	$f/6.3$	$f/8$	$f/11.3$	$f/16$	$f/22.6$	$f/32$	$f/45$
Relative exposure	1/5	1/3	5/8	1	2	4	8	16	32

## 10. CHOICE OF LENS AND CAMERA

For photography in the laboratory an 8 by 10 camera with a 10- or 12-inch lens will be found most satisfactory. The lens, of course, should be of the highest quality — the Zeiss Tessar, or equivalent lens. A 5-inch lens mounted so as to



Fig. 89. A 35 mm camera and auxiliary lenses.



fit in this camera should be available. It should be possible to place in the camera also a 50 mm, 35 mm, or 32 mm, lens for low-power photomicrography.

A great convenience in laboratory work is a groundglass back which contains two sliding metal plates that expose only one-fourth of the plate at one time. In much of the laboratory photography a number of experiments must be performed before hitting upon the proper technique. In photographing, for example, an erasure by infra-red light, several exposures may be necessary before the correct filter is discovered. By making a series of four exposures on one plate considerable time is saved in loading and processing.

The 35 mm (film) type camera is invaluable in a laboratory because of the great variety of uses to which it may be put — from fingerprint work to photomicrography. A complete set of auxiliary devices should be available (Fig. 89).

For field work, in addition to a 35 mm type camera, a 4 by 5 Speed Graphic or Graflex type camera (Fig. 90) should be used. A wide-angle lens will frequently be found necessary for photography in cramped quarters such as interiors of cars and rooms, or in photographing the entire front of a building. A telephoto lens should also be on hand, although it will be used with much less frequency than the wide-angle lens. Complete field equipment, then, would consist of a 4 by 5 camera with wide-angle and telephoto lenses, and a miniature camera with 50 mm and 35 mm lenses.

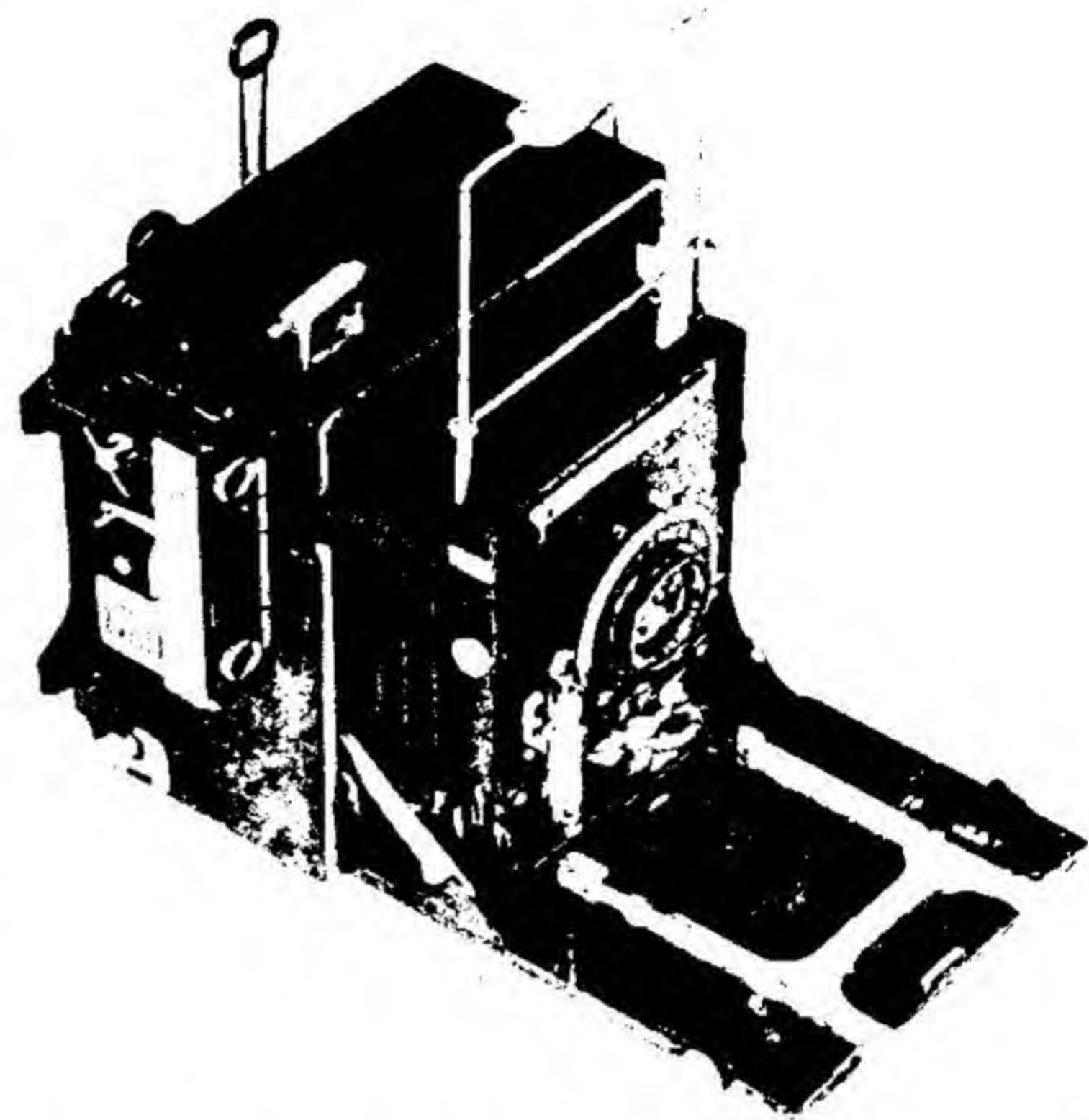


Fig. 90. A 4 × 5 camera for field use.

## PERSPECTIVE

### 11. THE PHOTOGRAPH AS A FAITHFUL REPRODUCTION

Perhaps the most serious objection raised against photographs submitted in evidence is the charge that photographs are at best distorted images of the original. Obviously, grossly distorted photographs such as Fig. 91 are rejected as evidence. Since so much of the criminalistician's work must be recorded photographically, and since these photographs are constantly subject to submission in court, it is frequently of great importance that true perspective be preserved. Naturally, in the vast majority of photographs perspective considerations are unimportant. For example, in photomicrographs and in great enlargements the spatial relations are a lesser consideration. However, in photographing the scene of a traffic accident, skidmarks, or interiors of rooms, faithful reproduction of distance relations is essential to a photograph which is acceptable in evidence.



It is impossible to reproduce perfectly in a photograph, which is a two-dimensional surface, the illusion of a three-dimensional space. This is true for



Fig. 91. Grossly distorted views.

the reason that the camera represents a single eye and can give no better than a monocular view of a subject. A photograph can be made to satisfy a single eye,

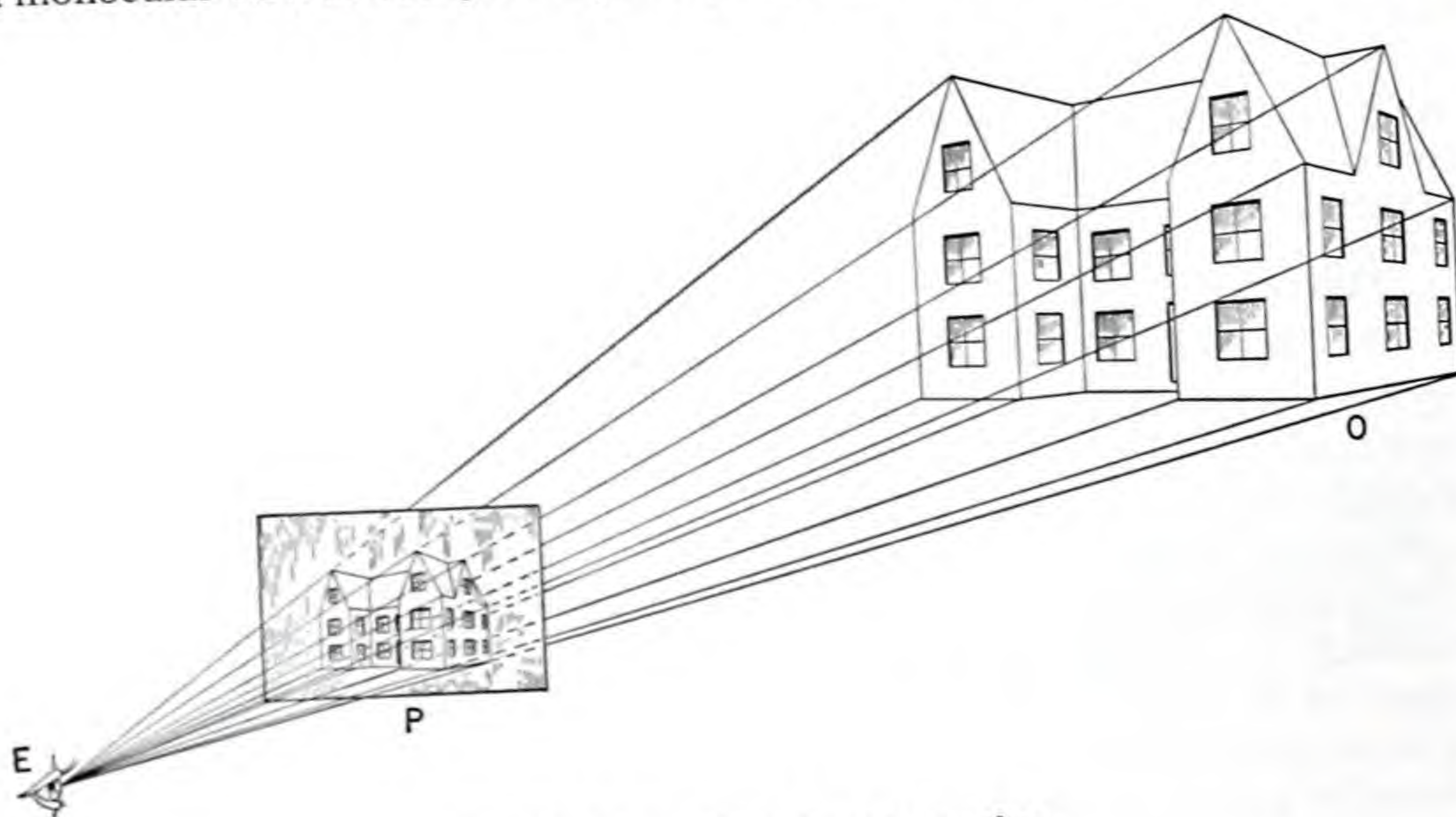


Fig. 92. Formation of a perspective.

for in the absence of binocular vision there is no depth except in memory and movement. Even for the single eye, however, the illusion of the photograph is



not perfect because of the advantage which the eye possesses in being able to gain some knowledge of the distance relations in the subject itself by focusing on different planes.

## 12. GEOMETRICAL DEFINITION OF PERSPECTIVE

If an object such as the house in Fig. 92 is viewed by the eye from the viewpoint  $E$ , a perspective would be obtained in the following manner. Place a transparent, vertical screen between the object and the viewpoint  $E$ . Connect every point in the object with the point  $E$  by straight lines. The intersections of the straight lines with the transparent screen would constitute a perspective. Viewed from  $E$  the trace on the screen would exactly hide the object from view. The relations between the lines in the object and the corresponding lines in the perspective are governed by simple geometrical laws. Without going deeply into the geometrical argument, we shall investigate the distortions resulting from viewing the perspective at a point other than the viewpoint.

## 13. DISTORTIONS

If the perspective is viewed from a point not on the line  $EP$  the various parts are no longer viewed at the same angles as the corresponding parts of the object itself and the result is a distorted view. This kind of deformation is not important to us at present because, as will be seen later, the perspective with which we are concerned is the photographic print and this is usually viewed along a line perpendicular to the print at the center.

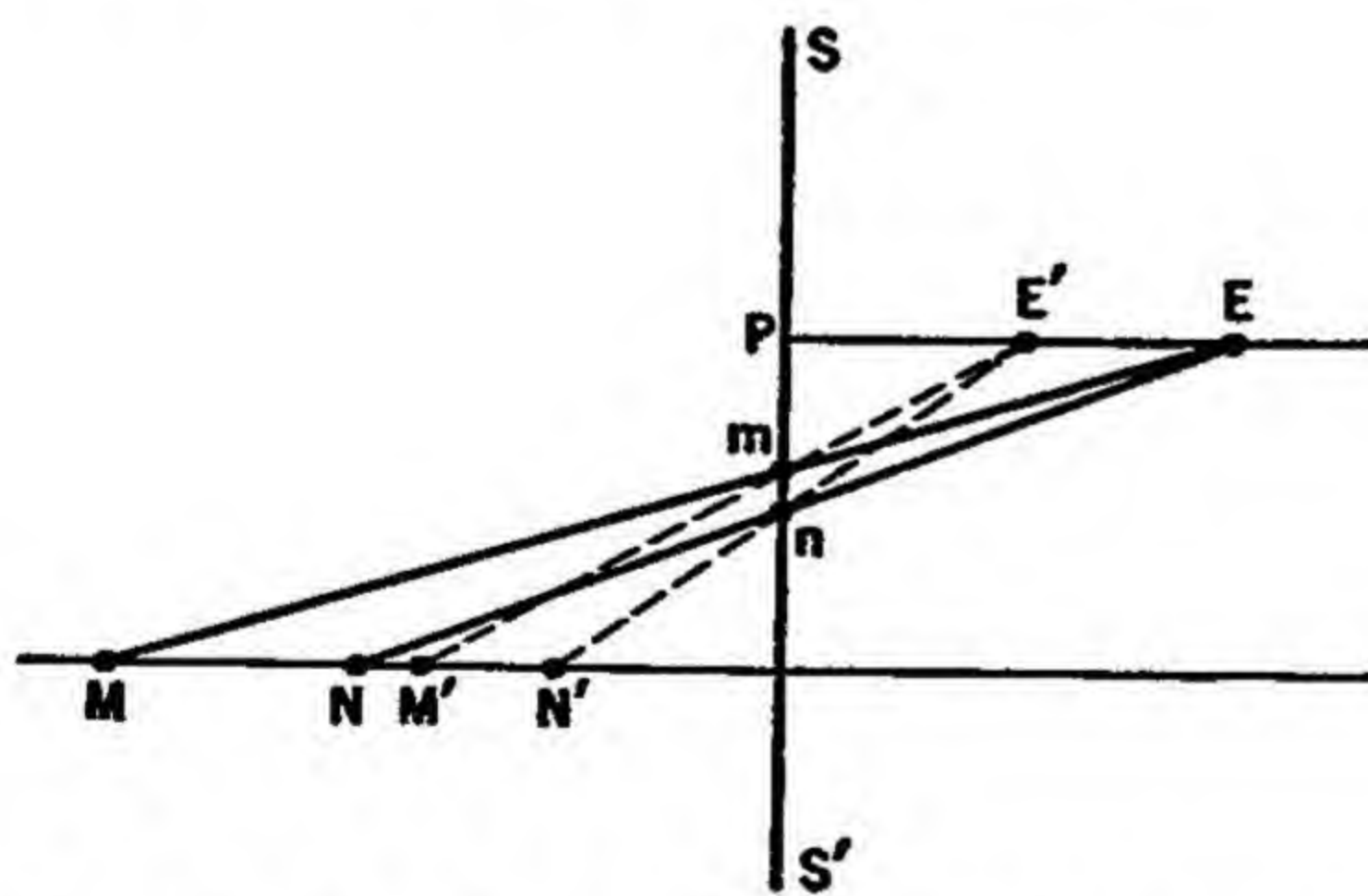


Fig. 93. Viewing a photograph from a point which is too near.

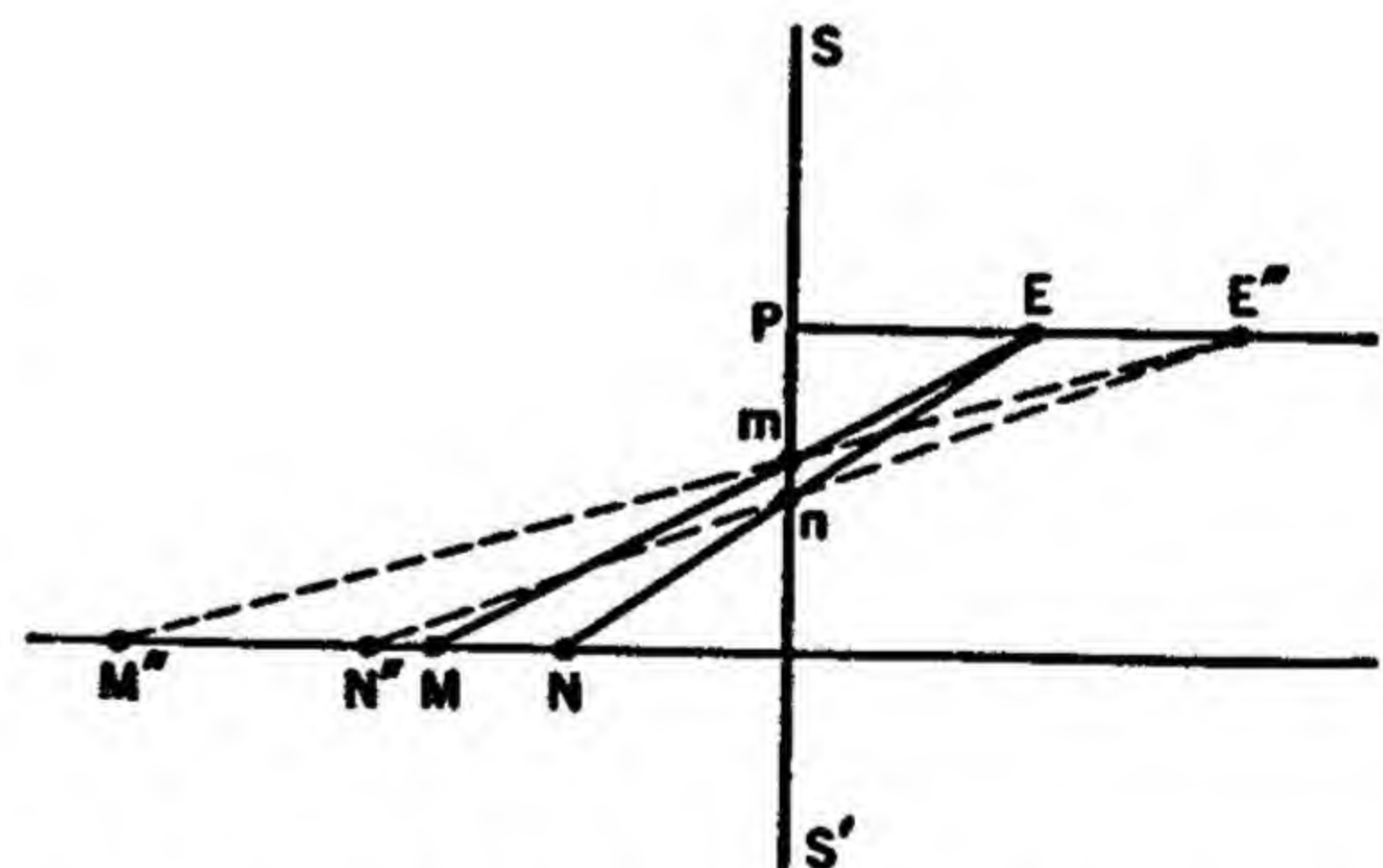


Fig. 94. Viewing a photograph from a point which is too far.

In photography the most common deformation is that resulting from viewing the perspective (print) from a viewpoint other than  $E$  but on the line  $EP$ . Figure 93 shows the result of viewing from a point  $E'$  where  $E'P$  is less than  $EP$ . The line  $SS'$  represents the perspective plane. The distance  $mn$  on the vertical is presented to the eye in the perspective. From the correct viewpoint  $E$ , the images  $m$  and  $n$  will appear to represent two points  $M$  and  $N$  in the horizontal plane. Their distance apart will be  $MN$ . If now the eye moves to  $E'$  and we draw the lines from  $E'$  through  $m$  and  $n$ , they appear to represent the points



$M'$  and  $N'$  in the horizontal plane with a distance between them of  $M'N'$ . Consequently the distance  $MN$  appears to be compressed. If the perspective is viewed at a distance  $E''$  greater than  $EP$ , the image  $MN$  is drawn out to  $M''N''$  as shown in Fig. 94. These distortions result in dimensions which appear exaggerated with reference to the position which the details appear to occupy in the object.

#### 14. THE PHOTOGRAPHIC IMAGE AS A PERSPECTIVE

The image formed on the groundglass of a camera is also a perspective. The viewpoint is at the center of the lens at a distance  $q$  from the groundglass. If the object is at a distance relatively great with respect to the focal length,  $q$  may be taken equal to  $F$ , the focal length. The photographic image is the same as the perspective which would be obtained if the eye were placed at the position of the lens and a trace made on a transparent screen placed at a distance  $q$  from the eye toward the object. It is well to state again that many assumptions have been made in this argument, chief among which is the condition that the angular magnification is unity. A general proof for optical systems would lead to a lengthy demonstration in geometrical optics.

#### 15. VIEWING THE PHOTOGRAPH

Since the groundglass image is a perspective with a proper viewing distance equal to the bellows extension of the camera, or the focal length when the object is at a relatively great distance, it follows that a contact print should ordinarily be viewed with the eye at a distance equal to the focal length of the camera. The normal reading distance is 25 cm, or 10 inches. The focal lengths of cameras vary, however, from about 3.5 cm to about 45 cm. For example, a Speed Graphic or Graflex type camera has a focal length of 5 or 6 in. Hence, a contact print from a negative made with such a camera would be correctly viewed at 5 inches. Again a contact print made from a 35 mm type camera of focal length 3.5 cm should be viewed at 3.5 cm. Few persons, however, have sufficient accommodation of the eye to permit viewing the print at such a close distance. If a print in which perspective is important is to be submitted for individual viewing by a judge or members of a jury, it must be made for a viewing distance of 10 inches (25 cm), at which distance it will naturally be held by the viewer.

#### 16. CORRECTION BY ENLARGEMENT

An enlargement too is a perspective. This fact enables us to print correctly negatives made with cameras of various focal lengths. A print from a negative made with a camera with a lens of 5 inches focal length should be enlarged to twice its size. It may then be viewed at 10 inches, the normal viewing distance, with a correct perspective. A photograph taken with a 5 cm lens — the 35 mm type camera — should be enlarged 5 times for correct perspective relationships at 25 cm viewing distance.



It is possible also to correct in enlarging a distorted perspective due to a tilting or turning of the plate with respect to the lens when the photograph is made. The angle of tilt of the plate and the focal length of the camera lens should be recorded. In enlarging, the negative and paper are set at the same angle of tilt. The enlarging lens employed should give a conjugate distance on the side of the negative equal to the focal length of the camera lens. A simplified way of accomplishing the rectification is to adjust the tilt of the paper until the vertical lines in the photograph are parallel.

### 17. CORRECTION BY REDUCTION

A negative made with a 17-inch telephoto lens cannot be readily printed for a viewing distance of 10 inches. One solution is to copy a contact print with a copying camera and then reprint for the proper viewing distance. This work, in general, will not be necessary since a viewing distance of 17 inches will not usually work any hardship on the viewer. It may, however, be difficult to convince a lay critic that this is a logical procedure. For special purposes viewing distances may be greater than 25 cm. An enlargement to be hung on a wall may have a viewing distance of a yard. For demonstrations before a jury or other audience great enlargements and correspondingly great viewing distances are permissible.

### 18. PERSPECTIVE AND FOCAL LENGTH

A common error among photographers, and even among writers on legal photography, is to associate wrong perspective with the focal length of the lens used. For example, the use of a wide-angle lens is sometimes deplored in this school of thought because of the seeming distortions in the contact print. The error here is easily recognized from the preceding discussion. The wide-angle lens may have a focal length of approximately 3 inches; therefore, a threefold enlargement is in order. Figure 95 is a photograph made with such a lens. Figure 96 is a print from the same negative enlarged for a viewing distance of 10 inches.

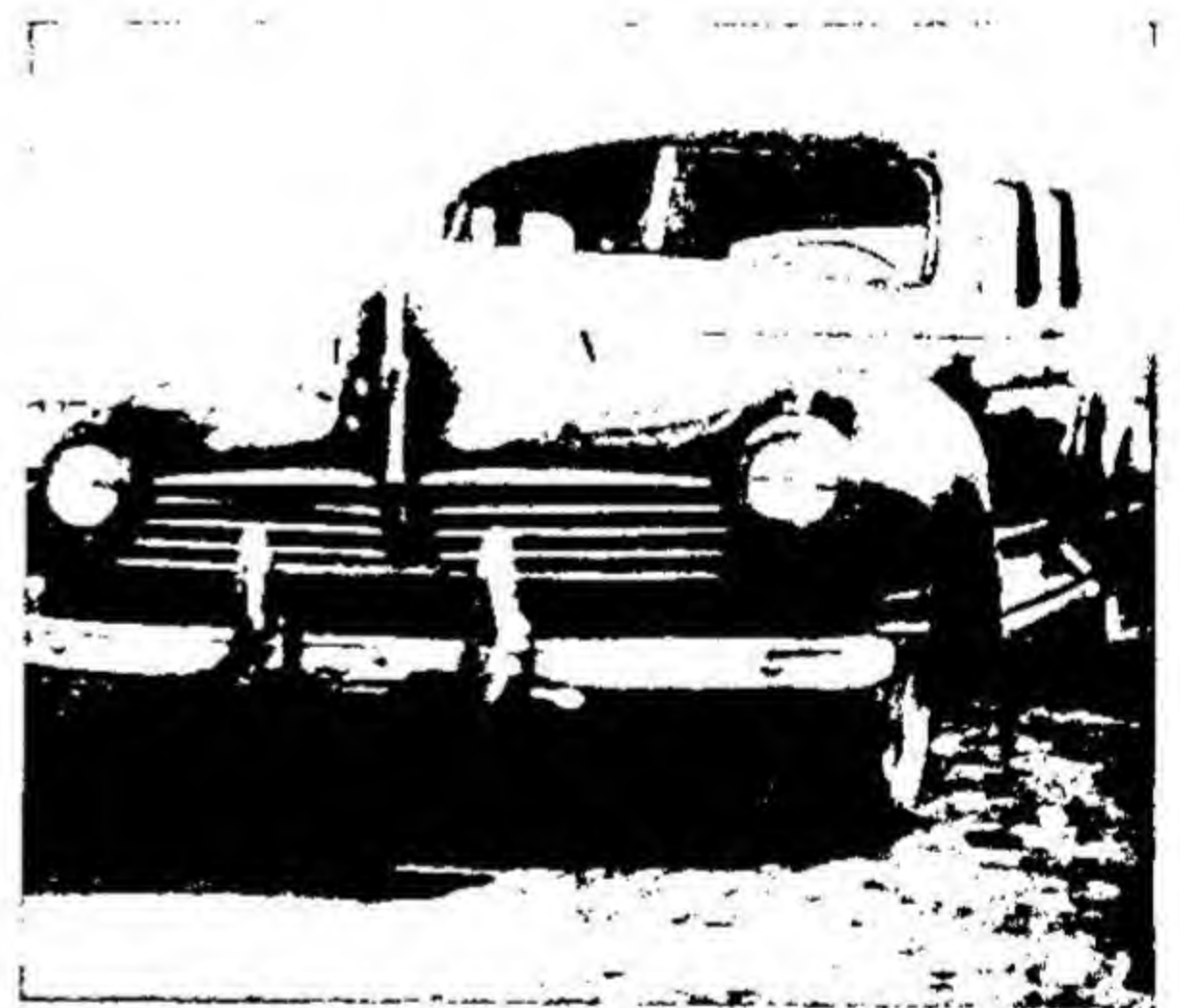


Fig. 95. A distorted view at normal viewing distance. The view is corrected by holding the photograph close to the eye.

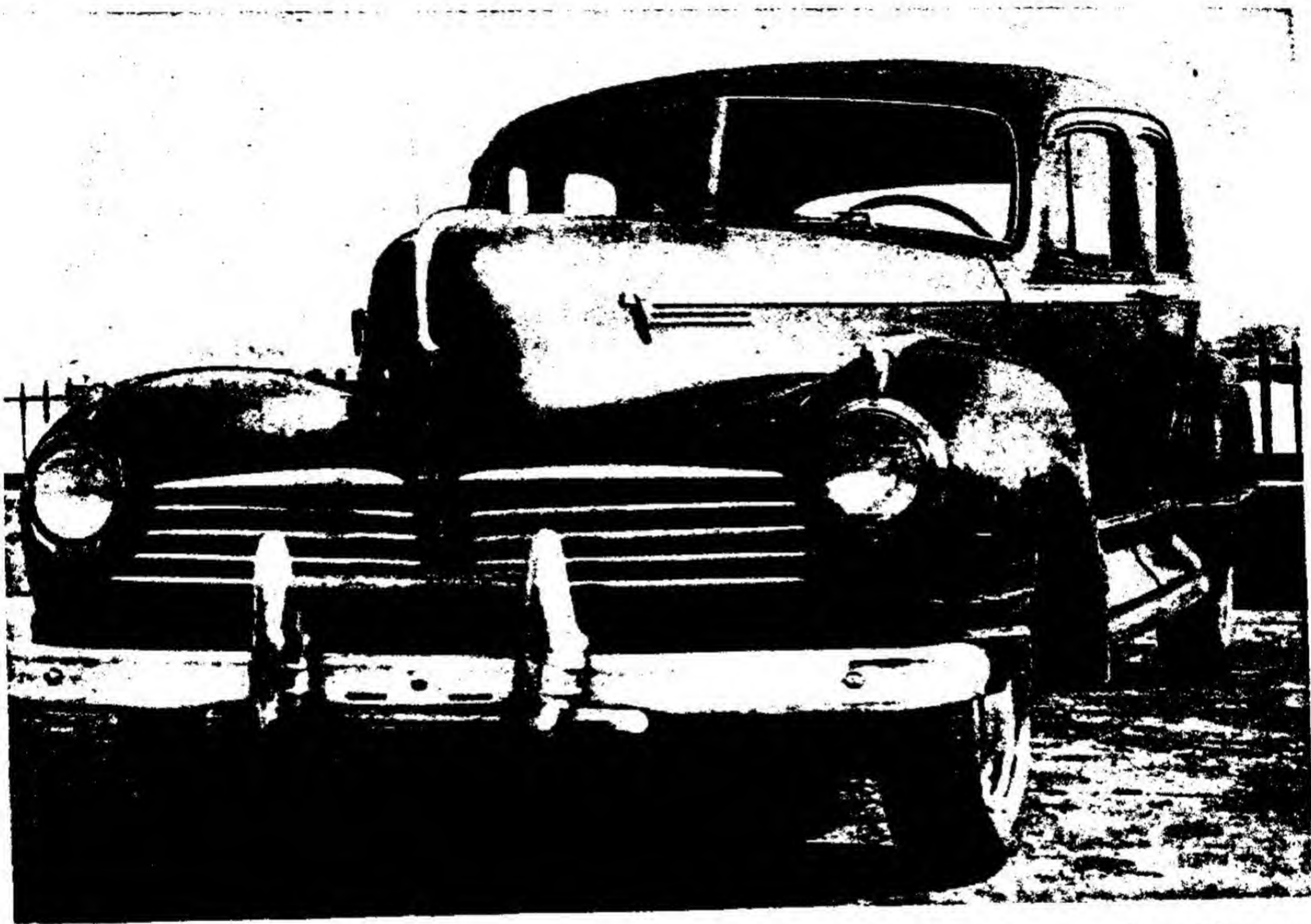
Similarly, a telephoto lens is sometimes accused of distorting a view by making distant objects appear too near to each other. The error here may be laid to a failure to view the photograph at a sufficiently great distance. In general perspective does not depend on the focal length of the lens used. The perspective of the lens is always correct, if the resulting photograph is viewed under the proper conditions.

### 19. GENERAL

We have established now several principles for correct perspective relationships. First, a contact print is viewed correctly only with the eye at a distance



equal approximately to the distance of the negative from the lens when the photograph was made. Second, photographs should ordinarily be printed for a viewing distance of 25 cm or 10 inches. We have so far treated only the viewing of the print. The viewpoint from which the photograph is made has not been mentioned. This viewpoint should be chosen independently of the focal length of the camera used. The choice should be guided as far as possible only by the purpose for which the photograph is intended, e.g., for the establishment of some point in the evidence by showing, perhaps, certain relationships among objects at the scene. The point of view will naturally be controlled also by the extent of the view which it is desired to include on the plate.



**Fig. 96.** The view in Fig. 95 corrected by enlargement for normal viewing distance.

The dimensions of the print should always be considered with relation to the viewing distance of the print. The eye can comfortably include a view which subtends at the eye an angle of approximately 50 degrees. It is for this reason that the diagonal of the plate of a camera is equal approximately to the focal length, for, as we have previously shown, under this condition the field of view subtends an angle of about 50 degrees at the lens. The cropping of enlargements as well as the original choice of point of view should be made with reference to the extent of the field of view at normal viewing distance.

Another precaution to be observed in legal photography is concerned with the angle at which the camera is placed. The camera should be fixed in the vertical plane, wherever possible. If the camera is equipped with a swing back, this condition may be fulfilled by maintaining the plate in the vertical plane.



This rule is given because of convention. Traditionally, artists have represented objects by a projection on a vertical plane. In a vertical projection horizontal lines converge; parallel vertical lines remain parallel. From this traditional representation the eye has become accustomed to the convergence of horizontal lines. If a photograph is made with the plate inclined at an angle, vertical lines will be found to converge, and the result will be a reproduction which is difficult for the layman to interpret. If, because of the lack of a swing back (or rising and falling front), a photograph is made with the plate inclined to the vertical, it is possible to correct for perspective by properly inclining the print in enlarging as described above.

## DEPTH OF FIELD

### 20. POINT IMAGES

Frequently, in photographing certain subjects, a necessity exists for clearly indicating the relationships of various details which are at different distances

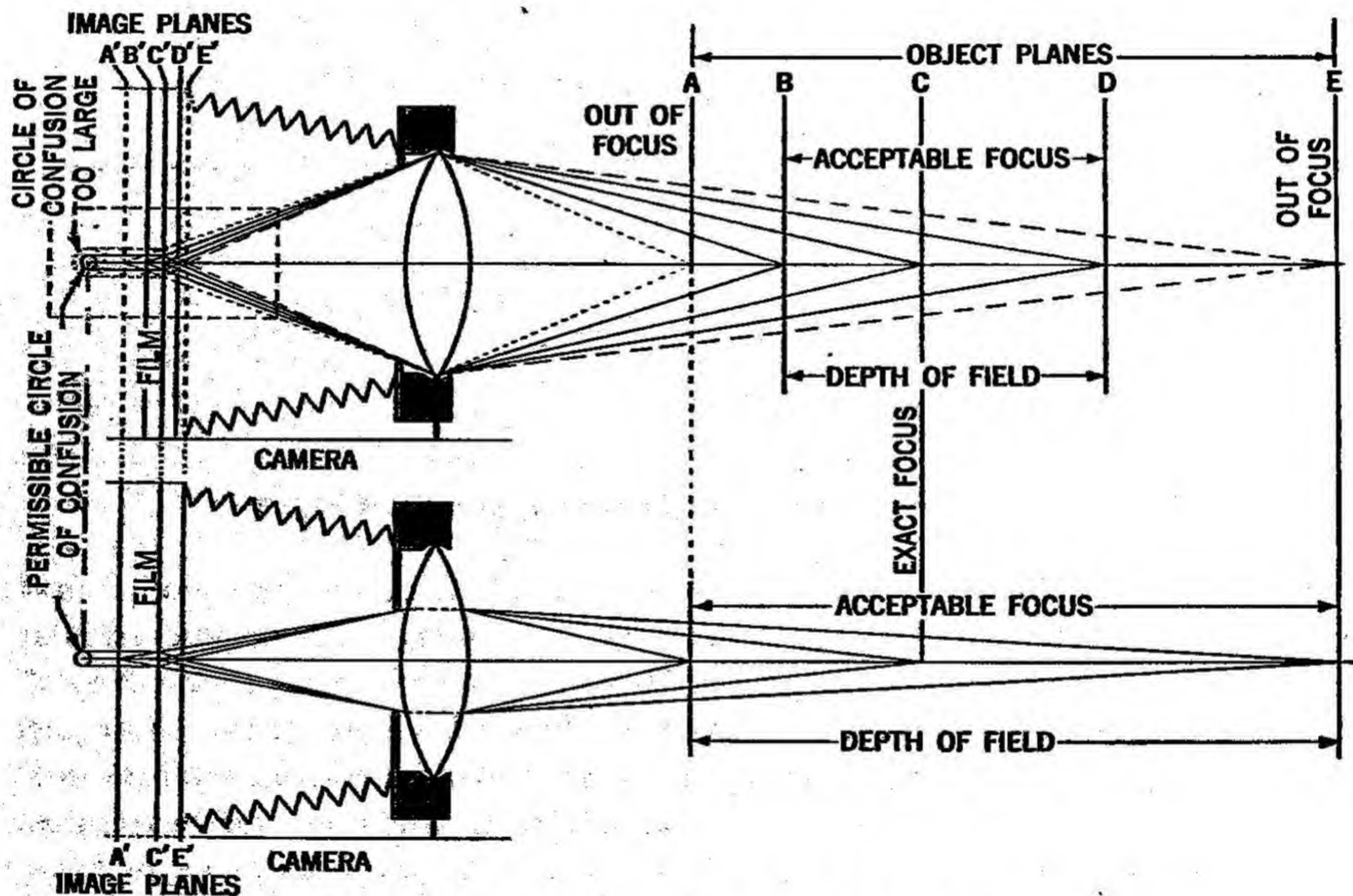


Fig. 97. Depth of field and the effect of "stopping down."

from the camera. For example, at the scene of a crime it may be desirable to show clearly in the photograph a body and a gun about six feet in back of the body. Both of these objects must then be in focus on the photographic plate. In the theory of a perfect lens system, however, only one plane in the object space corresponds to a given position of the photographic plate. In other words, for only one place in the object space will it be true that a point in the object will



be represented as a point on the plate. Points in other planes of the object space will be represented by circles on the plate. These facts are illustrated in the upper half of Fig. 97. The plane  $C$  is the plane on which the camera is focused. The corresponding image plane is the film, located at  $C'$ . Points in plane  $C$  are represented as points in the plane  $C'$ , the film. For other object planes such as  $A$ ,  $B$ ,  $D$ , and  $E$ , true image planes are at  $A'$ ,  $B'$ ,  $D'$ , and  $E'$ . Rays from points in these planes intersect the film plane in small circles and do not converge to points at this plane.

## 21. CIRCLE OF CONFUSION

Fortunately, point images are not necessary in a photograph. A point may be represented as a circular patch within a certain limit and the resulting

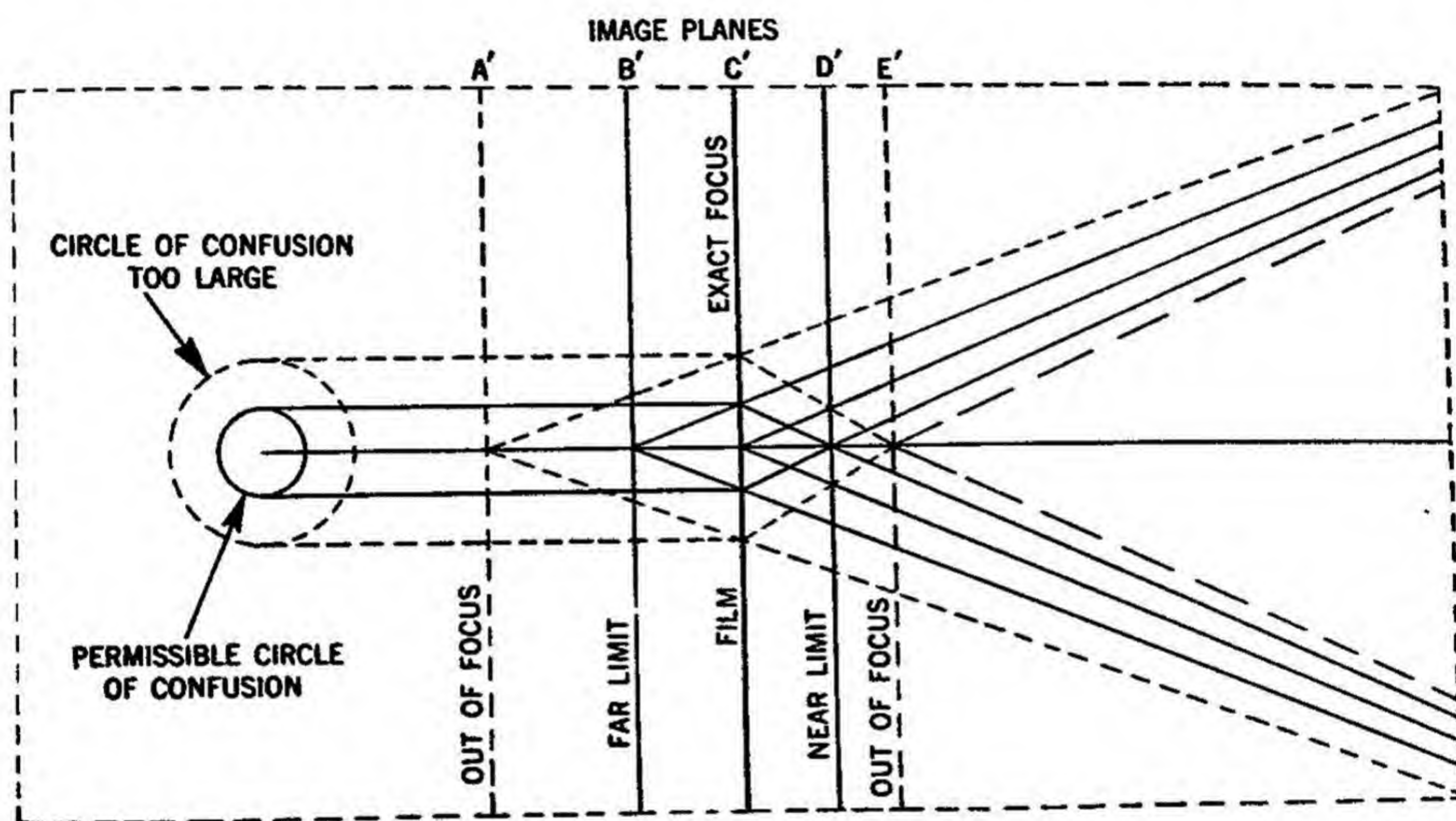


Fig. 98. Enlarged view of the upper left portion of Fig. 97.

diffuseness will not be discernible by the eye. A circle of sufficiently small diameter will appear as a point to the eye. The largest permissible circular patch is known as the *circle of confusion*. Its diameter will be represented by  $\zeta$ . In Fig. 98, which is an enlarged view of the left-hand portion of the upper part of Fig. 97, the inner circle is the circle of confusion. In this illustration rays from points in planes  $B$  and  $D$  subtend at the film, circles which are not greater than the permissible circle of confusion. Points  $B$  and  $D$  are said to be in focus. Points such as  $A$  and  $E$  which lie outside of the region  $BD$  subtend circles at the film which are larger than the circle of confusion, and hence do not appear to the eye as points in the resulting photograph. Points such as  $A$  and  $E$  are said to be out of focus. The distance or range  $BD$  in the object space within which points are represented in the film plane by circles of diameter less than  $\zeta$  is known as the *depth of field*.

An equation for depth of field can be given in several forms. One useful form is the following: If  $D$  is the depth of field,  $\zeta$  is the diameter of the circle of



confusion,  $m$  is the magnification, and  $f$  is the  $f$  number, we may write, approximately,

$$D = \frac{2\tilde{Z}(f/)}{m^2} \quad (15)$$

This equation assumes that the object is at a relatively great distance from the lens, a condition which holds in ordinary photography.

## 22. FACTORS AFFECTING DEPTH OF FIELD

If we consider  $\tilde{Z}$ , the diameter of the largest tolerable circle of confusion to be fixed, and if we compare photographic objectives under the condition that the  $f$  number\* is the same for all, it is seen that depth of field depends only on the magnification. From this it follows that all lenses have the same depth of field if the comparison is made under the same conditions. For example, if we wish to photograph a house 20 feet high, so that the image will be 4 inches high on the plate, the depth of field will be the same no matter what lens is employed, provided that the  $f$ /number is constant. This statement is contrary to the popular and erroneous concept of associating different depths of field with lenses of different focal lengths.

If now, the magnification is considered constant and the  $f$ /number variable, we may say approximately that depth of field varies directly as the  $f$ /number or relative aperture. Since the  $f$ /number is the ratio of the focal length to the effective aperture, by using a smaller diaphragm opening the depth of field is increased.

The effect of using a smaller diaphragm opening is illustrated in the lower half of Fig. 97. Rays from points in object planes  $A$  and  $E$  enter the lens at such angles that the circles which they subtend at the film plane now lie within the permissible circle of confusion. The depth of field has been extended from  $BD$  to  $AE$  by "stopping down" the diaphragm. A shorter focal length lens, also, will give a smaller  $f$  number and an increased depth of field. It is clear, however, that in each of these changes a sacrifice is made in illumination and, in the latter change, the magnification is affected. One conclusion to be drawn from this is that depth of field should not be considered as a function of one variable alone; but, for practical purposes, must be looked upon as a function of magnification, object distance, focal length, and aperture, which are not themselves independent variables. These relations can be summarized in the following manner:

- (a) Depth of field is inversely proportional to square of the magnification.
- (b) Depth of field is inversely proportional to the square of the focal length.

This follows from (a) since by equation (9),  $1 + \frac{1}{m} = \frac{p}{F}$ ,

where  $p$  is the object distance.

\* Strictly speaking, the term *plate illumination* should be used here instead of  $f$  number to convey the idea that we are comparing objectives under the same conditions of illumination. The  $f$  numbers of lenses of different focal lengths are not comparable except when the camera is focused for infinity.



- (c) Depth of field is directly proportional to the square of the object distance, for the reason given in (b).
- (d) Depth of field is directly proportional to the  $f$ /number or relative aperture, being greater the smaller the aperture.
- (e) Depth of field is directly proportional to the circle of confusion.



Fig. 99. Poor focus — the camera is focused on the head.



### 23. CALCULATING THE CIRCLE OF CONFUSION

The value of the diameter of the circle of confusion usually assumed is approximately  $\frac{1}{250}$  in. or 0.01 cm. A patch of this diameter is indistinguishable from a point at 10 inches, the normal viewing distance. Naturally if other viewpoints are selected, the diameter will vary accordingly. In general the



Fig. 100. Poor focus — the camera is focused on the chimney



maximum diameter of the circle confusion is approximately  $\frac{1}{1200}$  of the distance of the photograph from the eye in viewing from the center of perspective. This value can be deduced from the fact that the minimum angle subtended by the eye at two points which can just be resolved is approximately one minute of arc or 0.00029 radians.

The requirements of the circle of confusion must be made more exacting



Fig. 101. Correct focus — the camera is focused on the feet.



when the negative is to be enlarged later. If the enlargement is to be threefold, the diameter must be one-third of the least acceptable value for a contact print. For extremely fine lenses the usual value of the circle of confusion is in the region of  $1/500$  in. = 0.005 cm. With lenses satisfactory for scientific police work the limit of resolution of the emulsion should determine the circle of confusion. In other words, the size of the maximum permissible enlargement is usually determined by the appearance of "grain" in the image and not by any lack of definition due to the lens.

The circle of confusion which is assumed in any case should not be smaller than the smallest image of a point which the lens is capable of producing. It should be remembered that a poorer lens will have a larger circle of confusion (since less is expected of it), hence great depth of field is not associated with good objectives.

In equation (15) it is stated that depth of field is inversely proportional to the square of magnification. It is possible to take advantage of this fact by using a 35 mm camera wherever great depth of field is required, whether in laboratory or other work. The magnification in this case is quite small, and the depth of field is consequently great. This gain in depth of field is not lost in enlarging as long as the enlarging is within the limits set by the graininess of the negative.

## 24. MAXIMUM DEPTH OF FIELD

In laboratory work and at the scene of a crime, obtaining the required depth of field frequently presents a problem. Often some sacrifice must be made at either or both ends of the subject. In order to obtain *maximum depth of field* in relation to an object of which the near plane is at a distance  $r$  from the lens, and the far plane is at a distance  $s$ , the camera should be focused on the plane  $q$ , which is given approximately by

$$q = \frac{2rs}{r + s} \quad (16)$$

## 25. HYPERFOCAL DISTANCE

In outdoor photography (or in photographs of large rooms, made with short focal length cameras) practical use can be made of the concept of *hyperfocal distance*. This is defined to be the object distance for which the depth of field will just reach to infinity. When the bellows extension of the camera is equal to the focal length of the lens, the objects which are in acceptable focus are said to be at *infinity*. By increasing the bellows extension, objects nearer to the camera will come into focus while those at infinity will still remain in focus. A point in the bellows extension is finally reached where a further increase will cause the objects at infinity to go out of focus. The camera is now focused on the *hyperfocal plane*. On the near side of the hyperfocal plane the subject will be in focus down to a distance of one-half the hyperfocal distance. In other words, when the camera is focused on the hyperfocal plane, the permissible depth of



field extends from a point at a distance of one-half the hyperfocal distance to infinity. The hyperfocal distance  $H$  can be expressed by the equation

$$H = \frac{F^2}{(f/)\mathcal{Z}} \quad (17)$$

If we wish to print a photograph for the normal viewing distance of 10 inches, the ratio of enlargement should be, as we have seen,  $10/F$ . The circle of confusion must then not exceed  $F/1200$  inches. Substituting this value of  $\mathcal{Z}$  in the last equation we have

$$H = \frac{100F}{(f/)}, \quad (18)$$

where hyperfocal distance is expressed in feet, and focal length is in inches.

### EXERCISES

1. To photograph an object at a distance of 3 ft from the lens a 17-in. bellows extension is required. What is the focal length of the lens?
2. The maximum bellows extension of a certain type 35 mm (film) camera is 52 mm. For studio work it is possible to increase the image size by inserting tubes between the lens and the camera. When using a lens of 50 mm focal length, approximately what length of tube is necessary in order to achieve a 2X negative?
3. At the scene of a homicide it is found necessary to photograph the victim's body lengthwise and to include in the view a gun lying 4 ft from the body. The victim is approximately 6 ft in height. If a 4 by 5 camera with a lens of 5 in. focal length is used, approximately how far from the body must the camera be placed in order to include the desired view on the plate?
4. If the distance from the body and gun to the wall, before which the camera must be placed, is only 6 ft, what focal length lens should be used? What camera?
5. In a motor vehicle accident investigation it is found necessary to photograph, from the top of an embankment, a car which has fallen into a ravine 40 ft below. It is desirable to use a long focus lens for this purpose. A 14-in. lens is at hand. Is it possible to obtain a photograph with a camera of 10 in. bellows extension? What is the minimum bellows extension for a photograph with this lens?
6. Using a 4 by 5 or 8 by 10 camera, photograph a tall building from the street, first with the plate and lens board parallel to the face of the building and then with the plate and lens board inclined at an angle. Estimate this angle (e.g., approximately  $40^\circ$  from the vertical). Make contact prints of both photographs and compare the perspective of each. Try to correct the perspective of the second by enlarging and tilting the board holding the paper. Compare the angle at which the board must be tilted with the angle at which the photograph was taken.
7. Using a miniature camera with 35 mm or 50 mm focal length lens, photograph an automobile at a distance of about 5 ft from the front of the car. Use an  $f/18$  opening. Make a contact print and observe the exaggerated appearance of the length of the car. Make an enlargement from the negative, which will give a normal perspective. (Enlarge to 7X for 35 mm lens, and 5X for 50 mm lens.)
8. What is the hyperfocal distance in feet for a lens of 7 in. focal length stopped down to  $f/4.5$ ?



9. In order that the acceptably focused range will extend from 22 ft to infinity, what is the largest  $f$ /opening that can be used with a lens of  $8\frac{1}{2}$  in. focal length?

10. A camera with a large plate is being used to photograph an object in the studio. It is desired to fill the plate with the image. The near point of the object is at 14 in. from the lens; the far point is at 19 in. On what distance should the camera be focused for maximum depth of field with relation to the object?

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# CHAPTER 13

## TONAL RELATIONS — FIDELITY AND CONTRAST

### THE NEGATIVE AND TONE CONTROL

Quite often the aim of the criminalistician in photographing a subject is to reproduce faithfully in the negative the tones and gradations of light found in the subject. It is the purpose of the present chapter to investigate some of the principles which govern this process. To this end we shall first describe the production of the latent image and then study the relations of time and intensity of light in exposure. Briefly, the photographic process consists of the following four steps: (1) exposure of the plate or film, (2) development of the plate, (3) printing of the negative on paper, (4) development of the print. In exposing the plate a *latent image* is produced by the photochemical action of light on the sensitized emulsion. The photographic emulsion is a mixture of finely divided silver halide and gelatin. Three silver halides are used — chloride, bromide, and iodide. Bromide is by far the most important of these. When chloride and iodide are used, it is only in combination with bromide. By the effect of light upon the photographic emulsion, the silver bromide is changed. A reducing agent, the developer, darkens the silver bromide in those areas exposed to light more rapidly than in those areas where less light has fallen. The effect of the light, then, is to produce a latent image which the reducing agent transforms into a shadow picture or *negative*.

The faithfulness with which the negative will reproduce the original subject depends upon the tonal relations existing among the variously darkened areas. The study of these relations and the methods of measuring them is called *sensitometry*. For our purpose we shall discuss some of the laws relating to this absorption of light by the silver deposited on the negative after development. The following definitions are given:

#### 1. DEFINITIONS

##### Transparency

Light falling on the developed negative will be transmitted and absorbed in varying degrees depending upon the amount of silver deposit in the various



sections of the negative. If  $I$  represents the intensity of the light incident upon a certain area of the negative and  $I_x$  the intensity of the light transmitted in that area, the ratio  $I_x/I$  is termed the *transparency*. This ratio represents the fraction of the incident light that passes through the negative.

### Opacity

Opacity is the reciprocal of transparency. Hence,  $\text{opacity} = I/I_x$ . It is seen from this definition that opacity is a measure of the light that must fall on an area to transmit light of unit intensity.

### Density

The common logarithm of opacity is called *optical density*. Using the symbols  $D$ ,  $O$ , and  $T$  for density, opacity, and transparency, respectively, we have

$$D = \log_{10} O = \log_{10} \left( \frac{I}{I_x} \right) \quad (1)$$

The reason for this definition will be seen presently. Bouguer's law of absorption states that the intensity  $I_x$  decreases with the thickness of the material traversed. Further, equal proportions of light are absorbed by equal layers. This statement implies that the rate of absorption of light with respect to thickness of layers varies directly as the intensity of light at the depth  $x$ . If the intensity of light at the depth  $x$  is  $I_x$ , the law states that

$$\frac{dI_x}{dx} = -kI_x \quad (2)$$

where  $k$  is a constant called the *absorption coefficient*. The sign is negative, because the intensity decreases with  $x$ . Integrating, we have

$$\int_I^{I_x} \frac{dI_x}{I_x} = -k \int_0^x dx,$$

and

$$\log_e I_x \Big|_I^{I_x} = -kx \Big|_0^x;$$

whence

$$kx = \log_e I - \log_e I_x \quad (3)$$

or

$$kx = \log_e \frac{I}{I_x} \quad (4)$$

The more usual form of this equation is

$$I_x = Ie^{-kx} \quad (5)$$

The right side of equation (4) is simply the logarithm of the opacity (except for a constant factor). The left side of the equation is an expression which would suggest the term *density*, not in the usual physical sense, but with the connotation of *mass* — the amount of light-stopping substance. We shall say, then, that  $D = kx$ , meaning that density is proportional to the mass of reduced



silver per unit area. The constant  $k$  would include surface density in the usual physical sense. Hence equation (4) is equivalent to equation (1).

Considerable liberty has been taken in using  $x$  as a measure of the light-stopping substance present. An increase in exposure does not necessarily increase the thickness of the silver deposit. It would be more accurate to say that exposure increases the number of dark grains in the same layer. The argument, however, does not depend on a strict interpretation of  $x$ . Our purpose thus far has been simply to give some physical significance to the definition of density as the logarithm of the opacity.

## 2. THE PERFECT NEGATIVE

A technically *perfect* photograph is one in which the brightnesses of the various sections of the printed image are in proportion to the brightnesses of the original subject. Similarly, the perfect negative is one in which the blacknesses are in proportion to brightnesses of the subject. From this we can say that the technically perfect negative is one in which the opacities are proportional to the exposures received from corresponding parts of the subject.

It is neither necessary nor desirable (nor possible) that this condition be fulfilled in the average photograph. The relation between opacities and exposures will be determined by the purpose of the photograph. We have mentioned the perfect negative as a preliminary to the understanding of the characteristic curve.

## 3. THE CHARACTERISTIC CURVE

If we plot a series of densities against the logarithms of the corresponding exposures, the resulting curve will bear the general shape of that in Fig. 102.

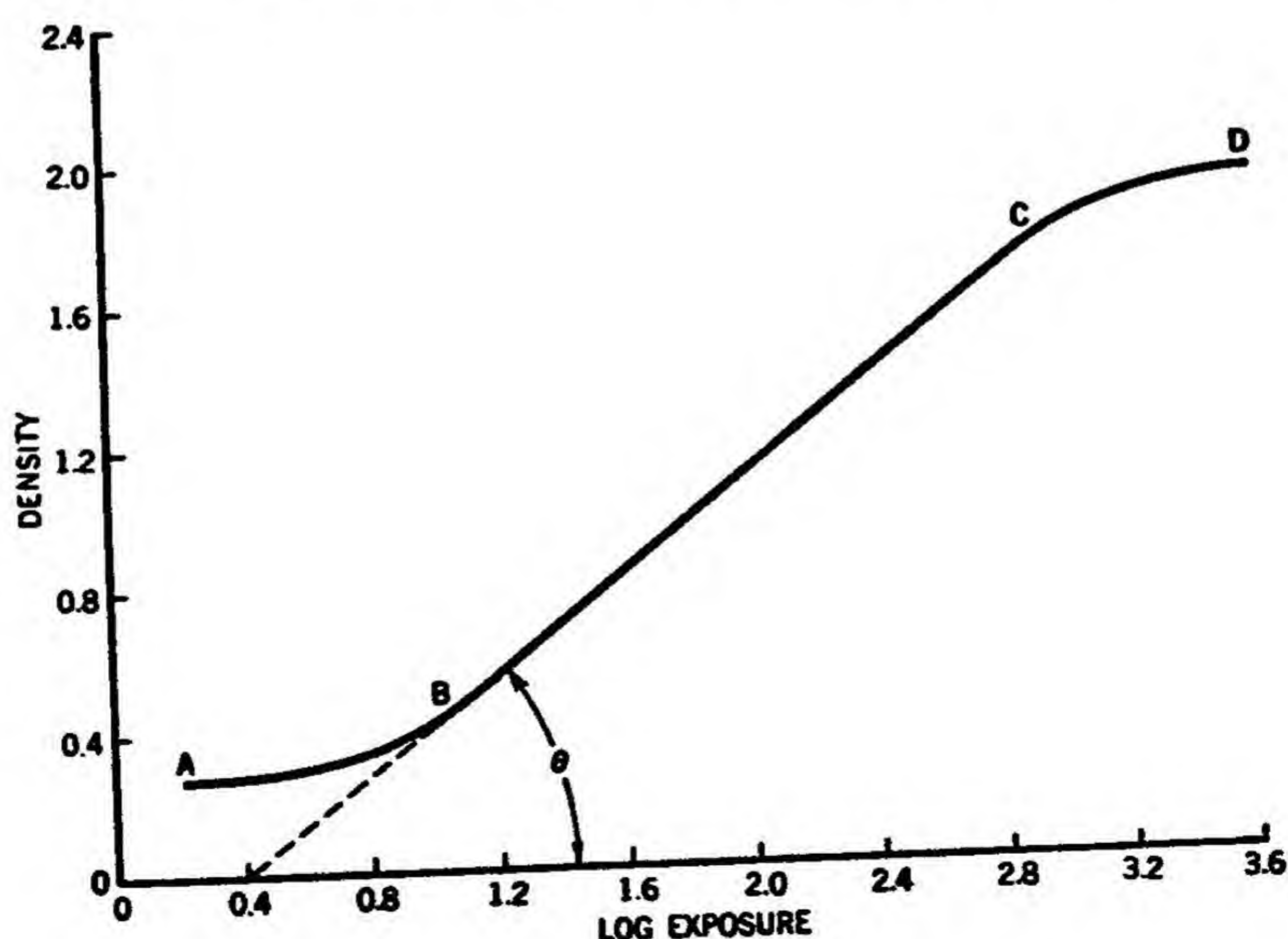


Fig. 102. The characteristic curve.



Our series of exposures may be a series of film strips which have received different times of exposure with the same illumination falling on the film or an ordinary negative in which the exposure varies because of the varying reflectance over the parts of the subject. The time of development is considered constant.

The reasons usually given for plotting density against the logarithm of the exposure instead of the exposure itself are: First, the range of exposures is very great; second, the nature of the relation between the variables becomes clearer. We may amplify these reasons by remarking that opacity and exposure  $E$  are, throughout a certain region, related by a power law such as:

$$O = KE^\gamma, \quad (6)$$

from which we have

$$\log_{10} O = \gamma \log_{10} E + \log_{10} K$$

or

$$D = \gamma \log_{10} E + M \quad (7)$$

where  $K$  and  $M$  are constants. It is logical, therefore, to plot  $D$  against  $\log E$  since the power law relation can be then clearly seen by the straight-line portion of the curve. The slope of the straight line  $\gamma$  (gamma) is the tangent of angle  $\theta$  in Fig. 102.

We may divide the characteristic curve into three parts: (1)  $AB$ , the part of increasing slope, indicating that density is increasing with exposure at an increasing rate; (2)  $BC$ , the constant slope or straight-line portion, indicating that density is increasing uniformly; and (3)  $CD$ , the part of decreasing slope, indicating that, with increased exposure, density is being added at a decreasing rate. These three parts are respectively called the regions of *underexposure*, *correct exposure*, and *overexposure*.

In a negative, the exposure of which falls within the region  $AB$ , we find disproportionate increases in density with increasing exposure. On examining the print it will be found that the shadows or darkest portions of the image are uniformly dark — there is practically no differentiation of tones in the shadows. The density increases sharply, however, in the region of the highlights. The case of overexposure finds the density increasing at its lowest rate in the region of the highlights; hence there is little differentiation of tones in the highlights.

If we use the term *contrast* to denote the rate of increase of density with the logarithm of the exposure, we may say that the underexposed negative lacks contrast in the shadows; the overexposed negative, in the highlights. This is equivalent to saying that loss of detail in shadows indicates underexposure; loss of detail in highlights indicates overexposure. For negatives suffering from these defects there is but one remedy — take the picture over again, using a proper exposure.

The straight-line section,  $BC$ , of the curve is considered the region of correct exposure, because in this region the rate of increase of density with the logarithm of exposure is constant. That this is an important and desirable condition may be seen from the fact that when this condition obtains, the power law is fulfilled.



A simplified mathematical argument will demonstrate the importance of this condition.

If  $\gamma$  (gamma) represents the slope of the straight-line section of the characteristic curve, a simplified equation for the curve would be

$$D = \gamma \log_{10} E + M,$$

or

$$\log_{10} O = \gamma \log_{10} E + M,$$

or

$$O = KE^{\gamma}, \text{ as we have already seen.}$$

Differentiating, we have

$$\frac{dO}{dE} = K\gamma E^{\gamma-1}. \quad (8)$$

Here we see the importance of  $\gamma$ , the measure of contrast, and its effect (as an exponent) upon the variation of the opacity with the exposure. If we take the case of  $\gamma = 1$ , we have

$$\frac{dO}{dE} = K$$

or

$$O = KE, \quad (9)$$

where  $K$  is a constant. This result means that the opacities are directly proportional to the brightness values in the subject. Such a negative (as stated before) is considered technically perfect — it is a theoretically true representation of the tones of the subject. If one area in the subject has a brightness double that of another, the negative of  $\gamma$  unity will have the corresponding opacities in the ratio of two to one. The condition of  $\gamma = 1$  is not a necessary one, however, as will be seen later. At present we shall investigate ways of controlling  $\gamma$  — namely, choice of film and length of development time.

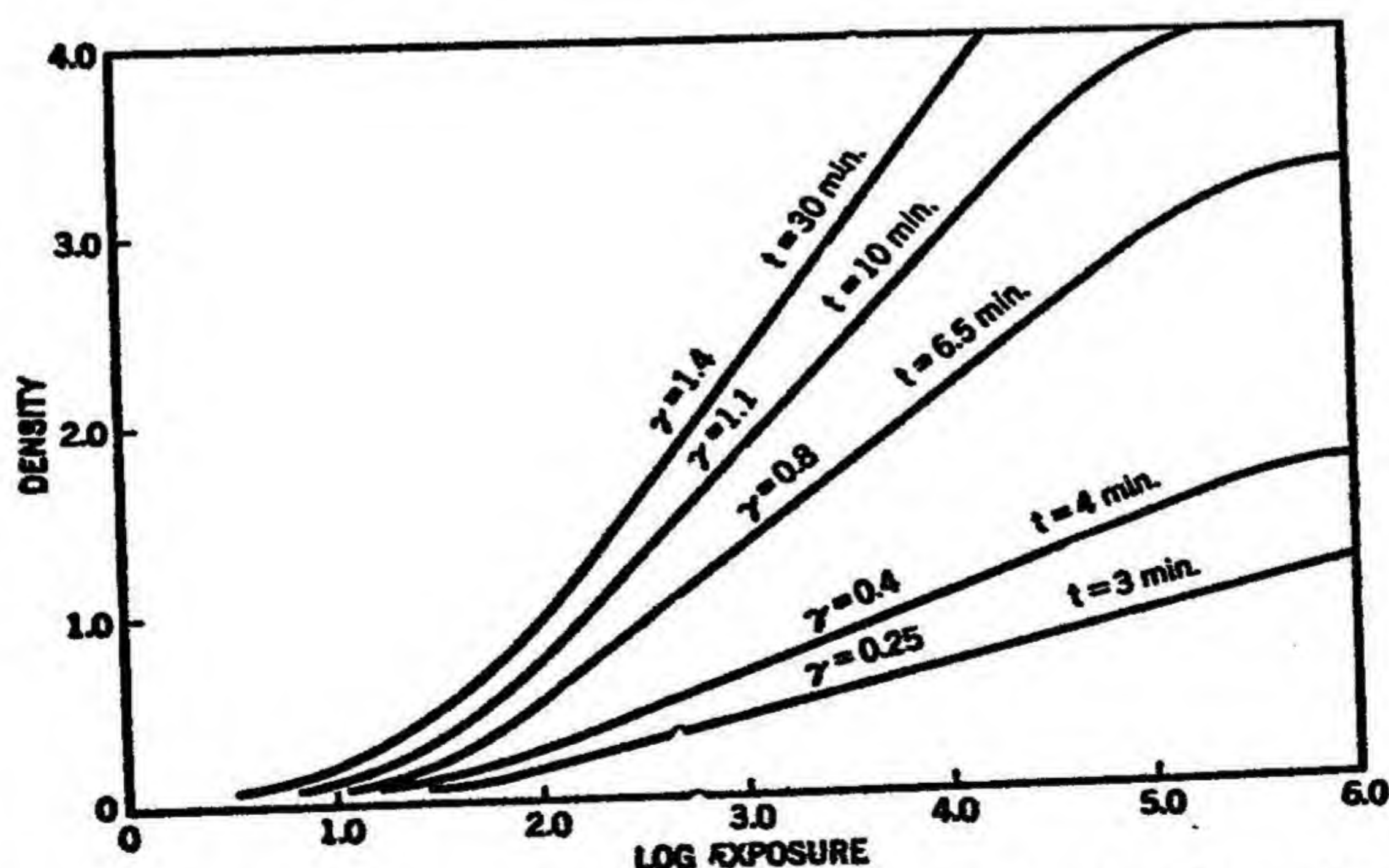


Fig. 103. Characteristic curves of negatives which have been given different times of development.



#### 4. GAMMA AND FILM

Films vary widely in the degree of contrast which they can yield. The speed of a film increases with the size of the silver bromide grains; the contrast increases with the uniformity of the size of the grains. It is found that an emulsion with large grains has a wide variation in grain size; the emulsion with small grains has greater uniformity of grain size. Hence we associate slower films with greater contrast. If we wish to photograph a document to emphasize certain characteristics, we use process film, which has high contrast. For a portrait we should select a film of low contrast.

#### 5. GAMMA AND DEVELOPMENT TIME

If we make several negatives of the same subject, giving the same exposure in each case, and if we give each negative a different development time, the resulting characteristic curves will resemble those of Fig. 103. The slopes of the curves are successively steeper as the time of development increases. Thus contrast increases with time of development. Figure 104 shows how  $\gamma$  increases with time of development for a particular film. The rate of increase is high at first and then falls off until a point is reached beyond which there is no further increase in  $\gamma$ . The value of  $\gamma$  at this point is called  $\gamma_{\infty}$  (gamma infinity).

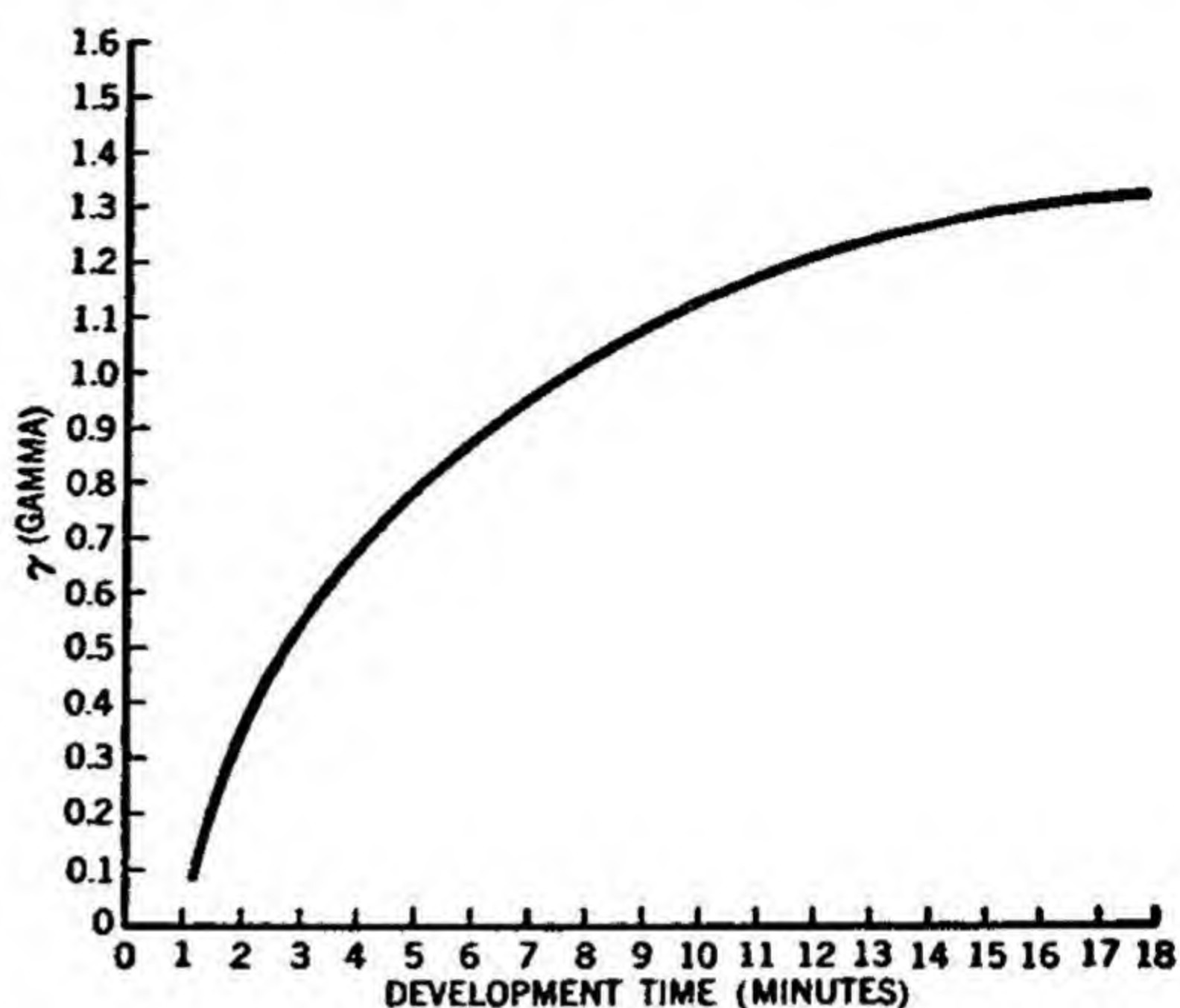


Fig. 104. Variation of contrast with development time.

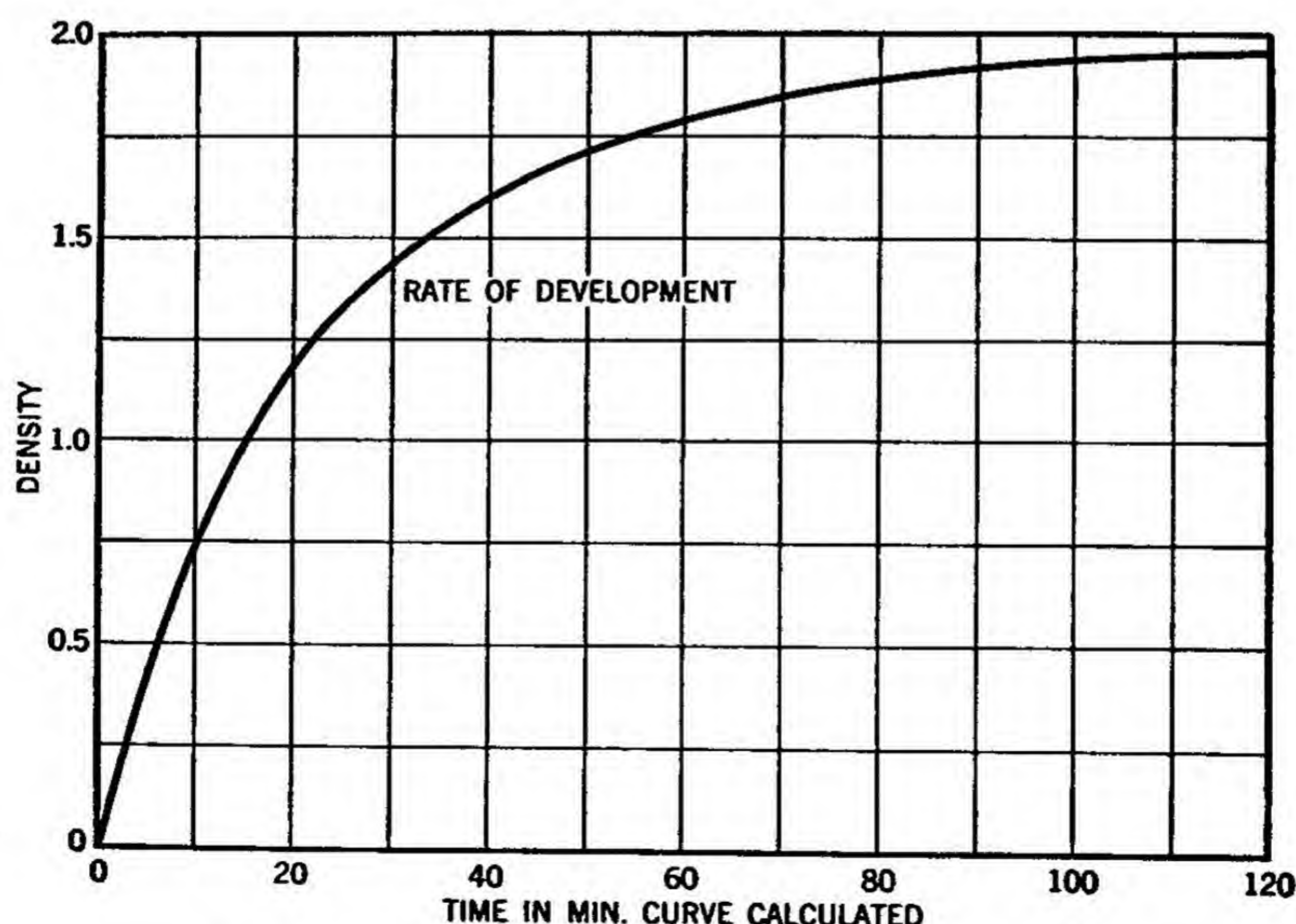


Fig. 105. Increase of density with development.



Figure 105 illustrates the manner in which density increases with development time for a given exposure. Density increases at a decreasing rate up to a certain limit,  $D_{\infty}$ , the end point. The equation of this curve may be written in simple form as

$$D = D_{\infty}(1 - e^{-kt}) \quad (10)$$

where  $k$  is a constant. We have seen from the equation  $D = \gamma \log_{10} E + M$  that  $D$  and  $\gamma$  are linearly related for a given exposure. Hence,  $\gamma$  also must satisfy an equation similar to that of the density. That is,

$$\gamma = \gamma_{\infty}(1 - e^{-kt}) \quad (11)$$

## SUMMARY

Thus far we have treated the formation of the negative image and the control of tone relationships. We have found that the critical factor in tone relationships is  $\gamma$ , the slope of the density-log  $E$  curve. The two important uses of  $\gamma$  in our work are: (1) to yield a fairly true photographic rendition of tones; (2) to increase contrast so that the photograph will emphasize details not readily perceived by the eye. The subject of contrast must, however, be further considered with relation to the end product — the positive.



Fig. 106. Photograph of the scene of the crime, using a film of average contrast.

As an example of how control of contrast can be used to distort a photograph, it is worth while to cite an instance which occurred in a civil suit. The plaintiff was suing a city for damages incurred by an accident caused by a hole in the sidewalk. It was maintained by the plaintiff that the hole was of considerable depth. A photograph was produced in evidence, showing the sidewalk interrupted by a black abyss. On further investigation by the defense it was found that the photograph had been deliberately underexposed so that no



detail was visible in the hole. The hole was later shown to be only an inch or two in depth. An example of tonal distortion by the use of the wrong type of film is shown in Figs. 106 and 107. In Fig. 106 a film of average contrast was used; thus the detail of the envelope, hat label, and gun are visible. In Fig. 107 process film was used with the resulting disappearance of these details.



Fig. 107. The same scene, using a film of excessive contrast. Note the loss of detail in the hat label, letter, and gun.

## CONTRAST IN THE POSITIVE

### 6. TONAL RELATIONS IN THE FINISHED PHOTOGRAPH

The emulsions of positive materials — transparencies or prints — are essentially the same as those of films, differing mainly in speed. Hence, the theory of the reproduction of the tones as outlined in the preceding paragraphs is applicable also to positive materials. The relation of tones in the finished print depends upon both the contrast of the negative and also of the positive. We shall illustrate this point by a simple mathematical argument in which the positive material is a transparency such as a lantern slide or motion picture film.

Let us consider two areas of a certain subject, say an outdoor scene, and the corresponding two areas of the printed reproduction. If the brightnesses of the areas in the print are proportional to the brightnesses in the subject, the print can be said to be a satisfactory reproduction. We investigate now the conditions under which such a reproduction can be made.

The relation between the exposure  $E$  of a negative, the intensity  $i$  of the light falling on it, and the time  $t$  of exposure can be approximately represented by equation (12) of Chapter 12.

$$E = it \tag{12}$$



Since we are considering only one negative,  $t$  is constant. If in place of  $i$  we write  $B$ , the brightness of the area, we have

$$\frac{E_1}{E_2} = \frac{B_1}{B_2} \quad (13)$$

where the subscripts refer to the two areas of the subject being considered — for example, a section of a cloud and a section of a tree in an outdoor photograph.

Using the simplified relation  $O = KE^\gamma$  (equation 6), we have

$$\frac{O_1}{O_2} = \left(\frac{E_1}{E_2}\right)^{\gamma_n} \quad (14)$$

and from equation (13)

$$\frac{O_1}{O_2} = \left(\frac{B_1}{B_2}\right)^{\gamma_n} \quad (15)$$

where  $\gamma_n$  is the  $\gamma$  of the developed negative.

Considering the printing of this negative, the exposure which the paper will receive in the two areas will be inversely proportional to the opacity of the negative in this area (this follows from the definition of opacity). If  $e_1$  and  $e_2$  are the exposures which the two areas of the print receive, we have

$$\frac{e_1}{e_2} = \frac{O_2}{O_1}; \quad (16)$$

hence, by substituting in equation (15),

$$\frac{e_1}{e_2} = \left(\frac{B_2}{B_1}\right)^{\gamma_n} \quad (17)$$

The quantity in the developed print corresponding to the opacity (properly transparency) of a negative is called the *reflectance* and will be represented by  $R$ . This quantity is defined by the equation

$$D_R = \log_{10} \frac{1}{R} \quad (18)$$

where  $D_R$  is called the *reflection density* of the positive.  $R$  will determine the brightness of any given area of the print under a given illumination. Corresponding to the relation  $O = KE^{\gamma_n}$  for opacity and exposure, we have for reflectance

$$R = \frac{1}{Ke^{\gamma_p}} \quad (19)$$

where  $\gamma_p$  is the  $\gamma$  of the developed print.

For the two areas of the print under consideration we have

$$\frac{R_1}{R_2} = \left(\frac{e_2}{e_1}\right)^{\gamma_p} \quad (20)$$

Substituting from equation (17)

$$\frac{R_1}{R_2} = \left(\frac{B_1}{B_2}\right)^{\gamma_n \gamma_p} \quad (21)$$



This ratio,  $R_1/R_2$ , determines the tonal relation of two areas in the finished print. It is seen that the relation depends upon  $\gamma_n\gamma_p$  the *gamma-product*.

## 7. THE GAMMA-PRODUCT

If in the original subject the cloud was 35 times as bright as the tree, and if the negative were developed to  $\gamma_n = 0.6$  and a paper of  $\gamma_p = 0.8$  were used, we should have

$$\frac{R_1}{R_2} = (35)^{0.48} = 5.5$$

That is, in the finished print the clouds would appear only five or six times brighter than the trees — definitely a flat photograph.

Since  $\gamma_n\gamma_p$  — the gamma-product — is an exponent, it has great effect on the reproduction of tones. Slight differences in gamma-products produce great differences in the relations of tones. Although a gamma-product of unity yields a technically correct reproduction, in practice variations are used according to the purpose of the photograph.

In portrait photography reduced contrast is desirable and a gamma-product of less than unity is preferred. In an outdoor scene a gamma-product greater than unity is recommended to supply the contrast which is lacking to the eye in a monochrome reproduction of a colored scene.

Enhanced contrast is often needed in laboratory work. Frequently the purpose of a laboratory photograph is the discovery of detail. The camera can be used to reveal detail which is undetected by the eye because of the lack of sufficient contrast. The ability of the eye to perceive a brightness difference in two adjoining areas of a negative is called its contrast sensitivity. Over very wide ranges of brightness the contrast sensitivity of the eye is approximately 1.8 per cent. This means that the eye cannot detect any difference in the brightness of two adjoining areas, if brightness difference in the areas is less than 1.8 per cent of the brightness of one of the areas. This condition frequently occurs in photomicrography and document photography. To enhance the contrast, a contrasty film such as process is selected; development of two-thirds gamma infinity would be given and a print made on paper of high contrast.

The enhancement in contrast achieved by this procedure can be very great. It is possible, with process film, to achieve a gamma of 4. If a paper with a maximum gamma of 2.2 is selected, the gamma-product is then 8.8. This means that brightness differences of 0.5 per cent in the subject — which were imperceptible to the eye — are rendered in the print as differences of 4.4 per cent, which are readily perceived by the eye.

## 8. PHOTOGRAPHIC PAPER AND DENSITY

For negatives we defined density as the logarithm of the reciprocal of the transparency. In the paper print, as we have seen, the analogue of transparency of the negative is reflectance. In other words, to measure blackness or silver



density in a print we must define density by equation (15). The problem of density in prints is somewhat complicated by the characteristics of paper. Exposure does not increase the density of a print so as to give an absolute black. There is always a certain minimum amount of light reflected from the paper. This is due to the fact that the reflection of light from a paper is not dependent on the silver deposit alone. There are three surfaces in a photographic print: the gelatin, the silver deposit, and the paper itself. Increase in silver density

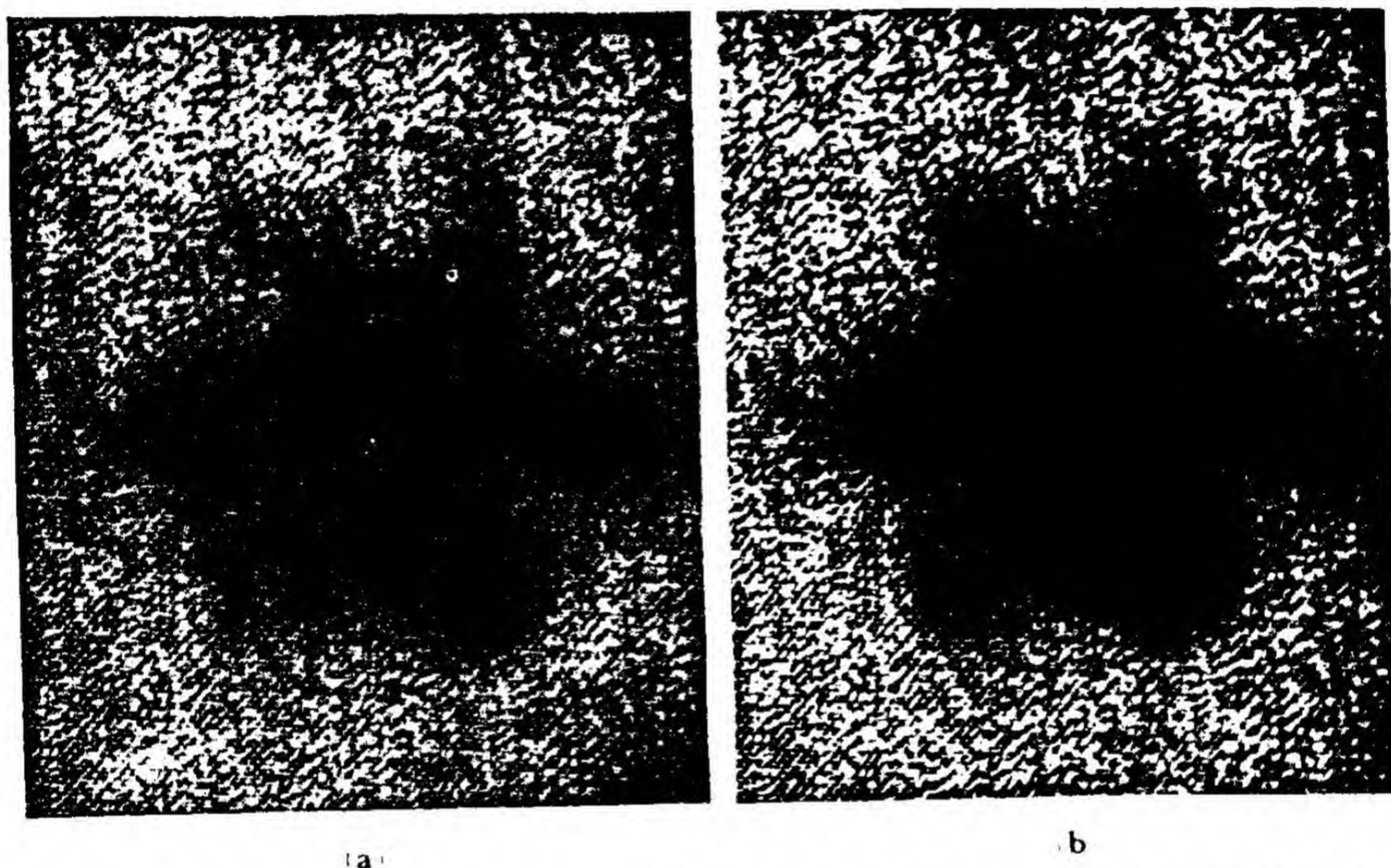


Fig. 108. Powder mark surrounding a bullet hole in cloth, photographed (a) with a high-speed film; (b) with a process film.

affects the light reflected from the paper, which is the lowest surface, but does not affect the light reflected from the gelatin and the silver deposit. The maximum black obtainable from paper reflects about 2 per cent of the incident light. The maximum density of a glossy paper is approximately 1.7; for semi-matte this maximum is 1.55; while for matte the maximum is 1.50. This limitation in density will, as we shall see, place a serious limitation on the capacity of a photographic print to represent faithfully the brightness scale of the original subject.

## EXPOSURE OF THE NEGATIVE

### 9. CHARACTERISTICS OF FILM

Speed, graininess, latitude, contrast, and color sensitivity are the five characteristics of a film which concern the scientific photographer. Color rendition will be treated in a separate section. Latitude and contrast are interrelated. Knowledge of these factors leads to control of tone reproduction.



# 10. LATITUDE

We have seen that for correct tone reproduction, the exposure time should be such that the exposures of the darkest and lightest areas of the subject will fall on the straight-line portion of the characteristic curve. The latitude of a film or paper is the ratio of the exposures at these points. In Fig. 109 the latitude of the film is the ratio  $OP/ON$  (exposure units). The straight-line portion  $BC$  of the characteristic curve does not, however, limit the usefulness of the negative. The toe  $AB$  and the shoulder  $CD$  of the curve also possess regions which

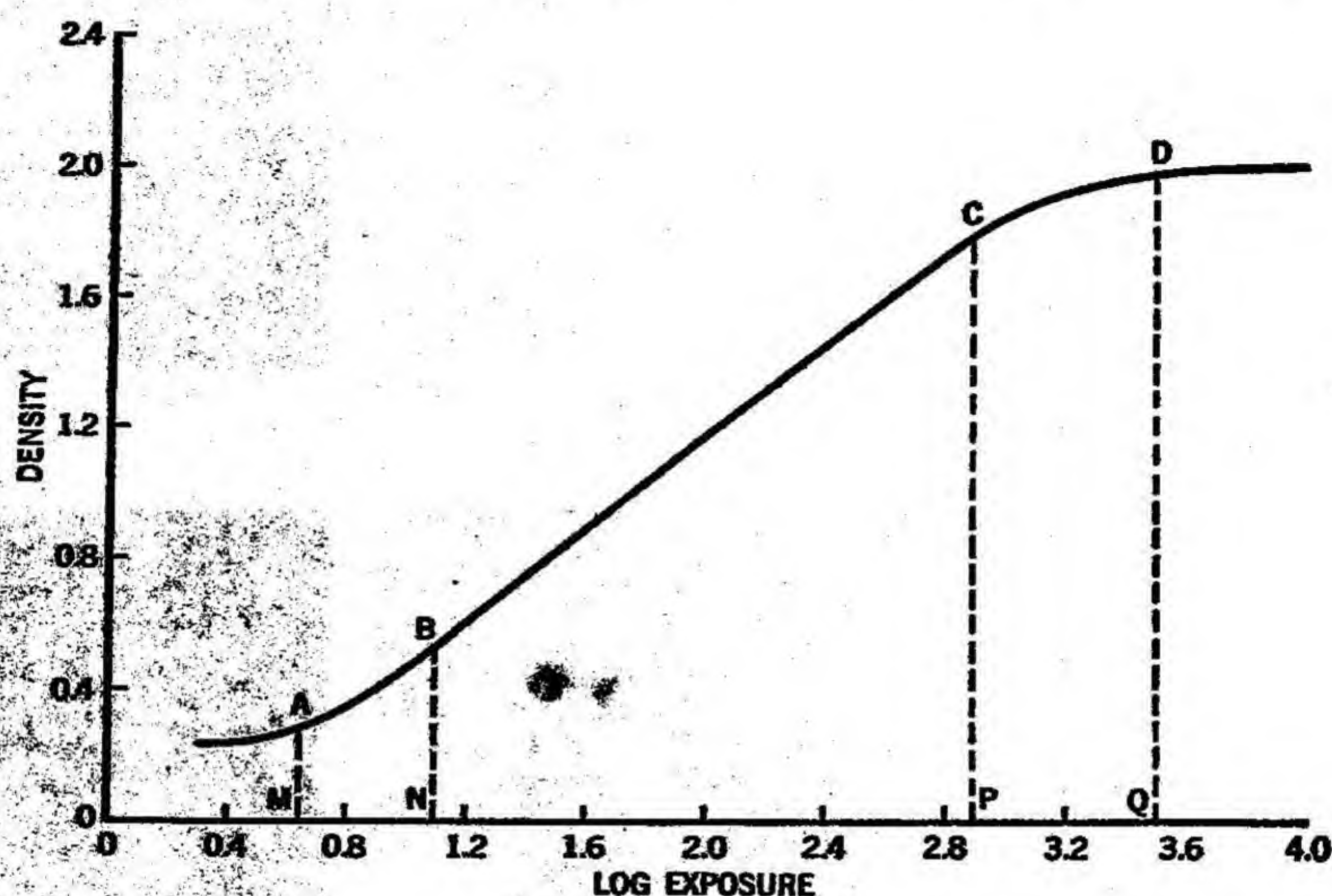


Fig. 109.

will yield perceptible density differences. The regions  $AB$  and  $CD$ , although possessing different contrast characteristics from the straightline portion  $BC$  are still useful. We define the projection  $MQ$  of the region  $AD$  on the log  $E$  axis as the *total scale* of the negative. The total scale, then, is the range of light intensities which will be reproduced as areas whose densities are perceptibly different to the eye. The total scale can be expressed in exposure or log exposure units; thus,

$$\text{Total scale} = \log_{10} (OQ) - \log_{10} (OM) \text{ (log exposure units)}$$

or 
$$\text{Total scale} = \frac{OQ}{OM} \text{ (exposure units).}$$

Ordinarily there is no single "correct" exposure of a negative. For example, if the latitude of the film is 1-70 and the range of brightness of the subject is 1-7, an exposure of 10 times the minimum exposure would still be a correct exposure. If a subject with a range of 1-50 in brightness is to be photographed, considerable care must be exercised to expose on the straight-line of a 1-70 film.

Ranges of brightness vary widely with the subject and conditions of illumination. The average outdoor scene may have a range of 1-150. Interiors will



average 1-50. In laboratory work ranges as great as 1-100 will be encountered in photographing evidence.

The latitudes of films vary considerably. A high-speed film with a range of 1-250 is available. Since the maximum range of papers is about 1-50, the chief

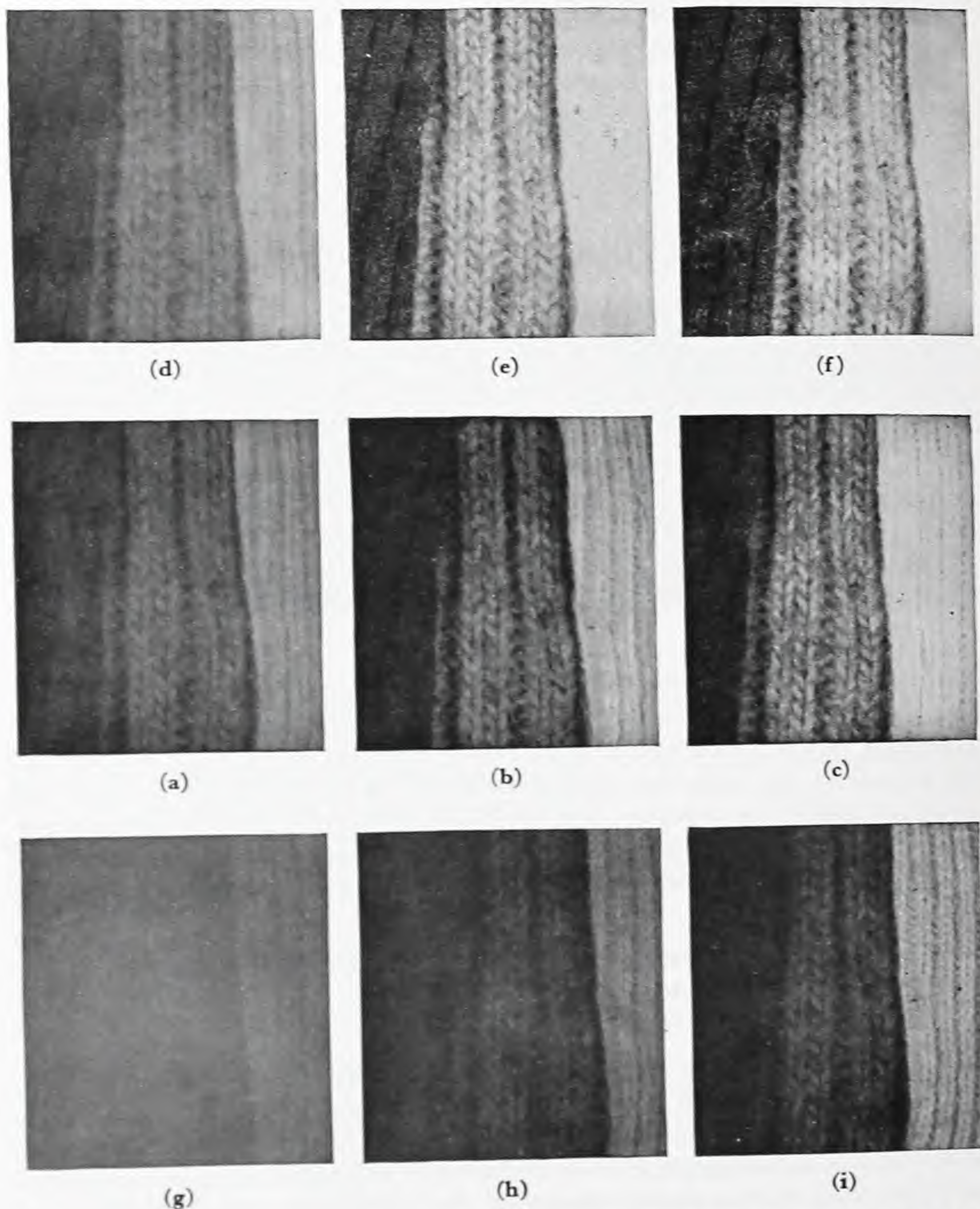


Fig. 110. Prints (on a paper of normal contrast) from nine negatives, illustrating the effects of varying exposure and development. See Table 4 on page 189.



value of this wide range in film is to permit deviations in exposure. Process film has a latitude of only 1–4, an extremely small range. This narrowness of range is always associated with great contrast. The subjects of latitude and contrast must be discussed together for a fuller understanding of the use of either.

## 11. CONTRAST

Again, we find in films a wide variation of this quality. A portrait film will have a gamma of less than unity; process film is capable of a gamma of four (development being constant). Hence, film may be chosen according to its potential contrast. In addition, we have already seen that contrast increases with time of development. By means, then, of choice of film and time of development, the operator may vary gamma from about 0.5 to 4.0.

By increasing contrast through lengthening of time of development, a shortening of the effective latitude of the film is brought about. This may be seen from Fig. 103 in which, for a given exposure, different development times have been given a film. The latitude of the film is proportional to the projection of the straight-line portion of the curve on the log exposure axis. This projection becomes shorter as the slope of the straight lines increases. Thus, by increasing gamma through choice of film or development, the effective latitude is decreased. This effect is described as *compression of the tone scale*. The opposite effect — increase of latitude — can be accomplished by decreasing development time.

In Fig. 111 where the same column of tones has been photographed

by using (a) portrait film and (b) process film, the sacrifice of latitude for contrast is apparent. (Normal development is assumed for each film.)

## 12. INCREASING CONTRAST BY COPYING

Where it is desirable to have great contrast in a negative, process film should be used. Contrast can be further increased in an existing negative by making a

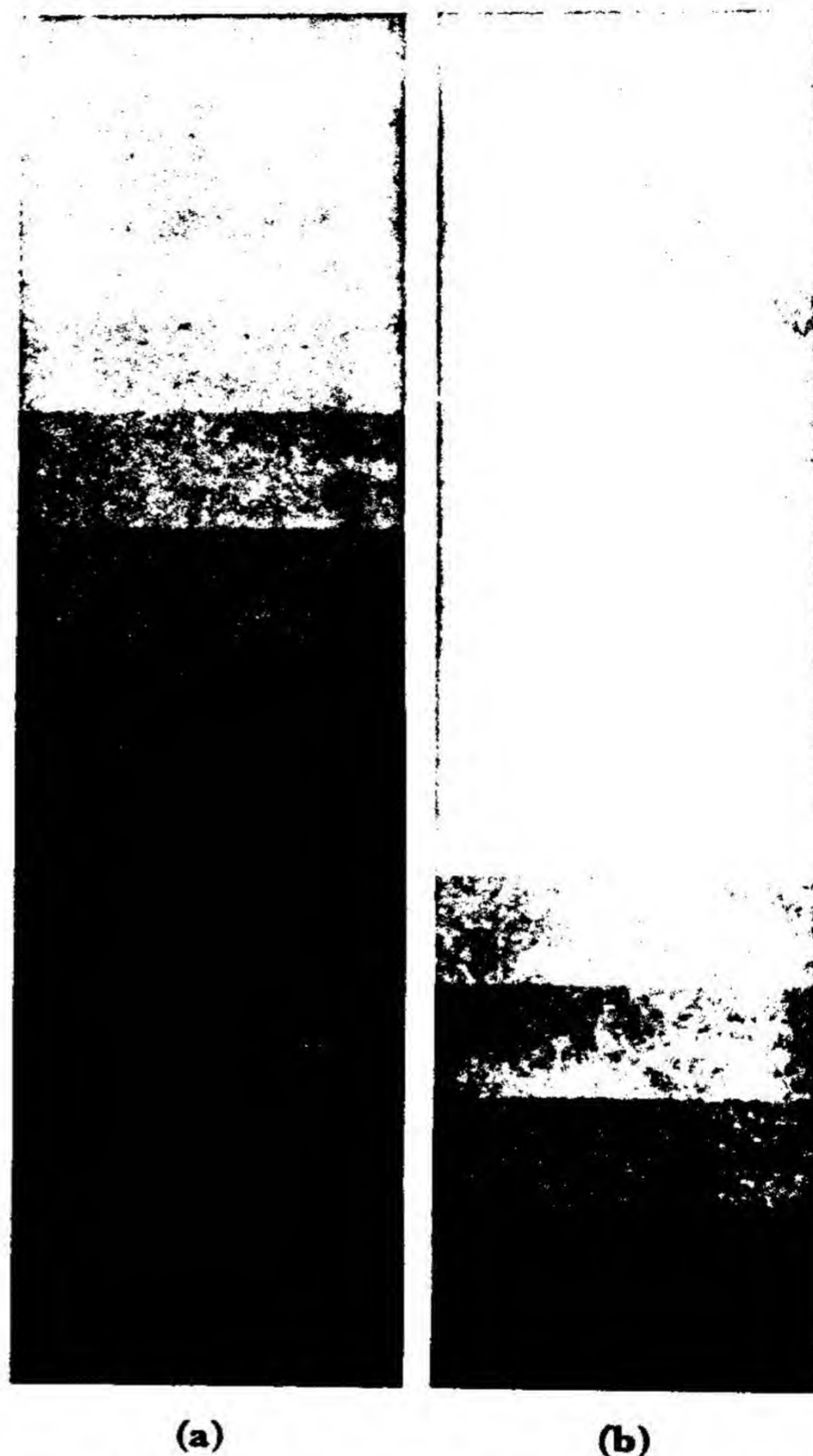


Fig. 111. Reproduction of tones, using (a) a portrait film; (b) a process film.



transparency of the negative on process film, and then making a transparency of the transparency. In other words, the negative and a sheet of process film are placed in a printing frame and exposed to an ordinary 60-watt ceiling light at six feet for a second or two. This film is now put through the developing process. Since it is a positive it must be recopied; hence the process copy is exposed on a second sheet of process film. The second sheet of film is then developed and printed. This procedure should be used only where extreme contrast is desired.

### 13. USE OF THE EXPOSURE METER

It has been stated that the effects of underexposure or overexposure are irreparable. Both of these conditions can be avoided by use of an exposure meter. The person using the meter must guess the proper exposure usually must guess varying from one-tenth to ten times his guess. This is especially true under poor lighting conditions.

For the best results, best learned from the manufacturer's directions. When a subject of great range of brightness is being photographed, readings should be taken on the brightest and darkest areas, and an exposure then chosen which covers this range. The latitude of the film should be taken into consideration when determining this exposure.

The exposure reading which is given by the meter is a correct value for the exposure time when the object is at infinity with relation to the focal length of the camera. In other words, when the bellows extension of the camera is equal to the focal length the reading is correct. If the bellows extension is greater than the focal length, the inverse square law for light intensity must be applied. For example, if  $t_m$  is the meter reading in seconds,  $F$  is the focal length of the camera,  $B$  is the bellows extension, and  $t_c$  is the correct exposure time at this extension, we have

$$t_c = t_m \times \frac{B^2}{F^2} \quad (22)$$

When the size of the photographic image is the same as that of the object we have  $B = 2F$ ; hence  $t_c = 4t_m$ .

The increase in exposure time necessitated by bellows extension becomes important only when the object is at close range. It is more profitable, perhaps, to discuss the exposure increase in terms of object distance. In Fig. 112 the factor by which the meter reading must be multiplied is plotted against the ratio  $R$  where

$$R = \frac{\text{object distance}}{\text{focal length}}$$

## EXPOSURE OF THE PRINT

### 14. THE SCALE OF A PAPER

We have seen that contrast in a negative is determined by the choice of film and the length of time of development. In the processing of prints, development



is almost always carried to gamma infinity, so that the variable factor within the photographer's control is the choice of paper. (It should be mentioned, however, that special papers are available with which contrast can be controlled by development.) Papers are usually numbered from zero to five in the order of increasing contrast. The choice of paper is determined by the character and purpose of the negative at hand.

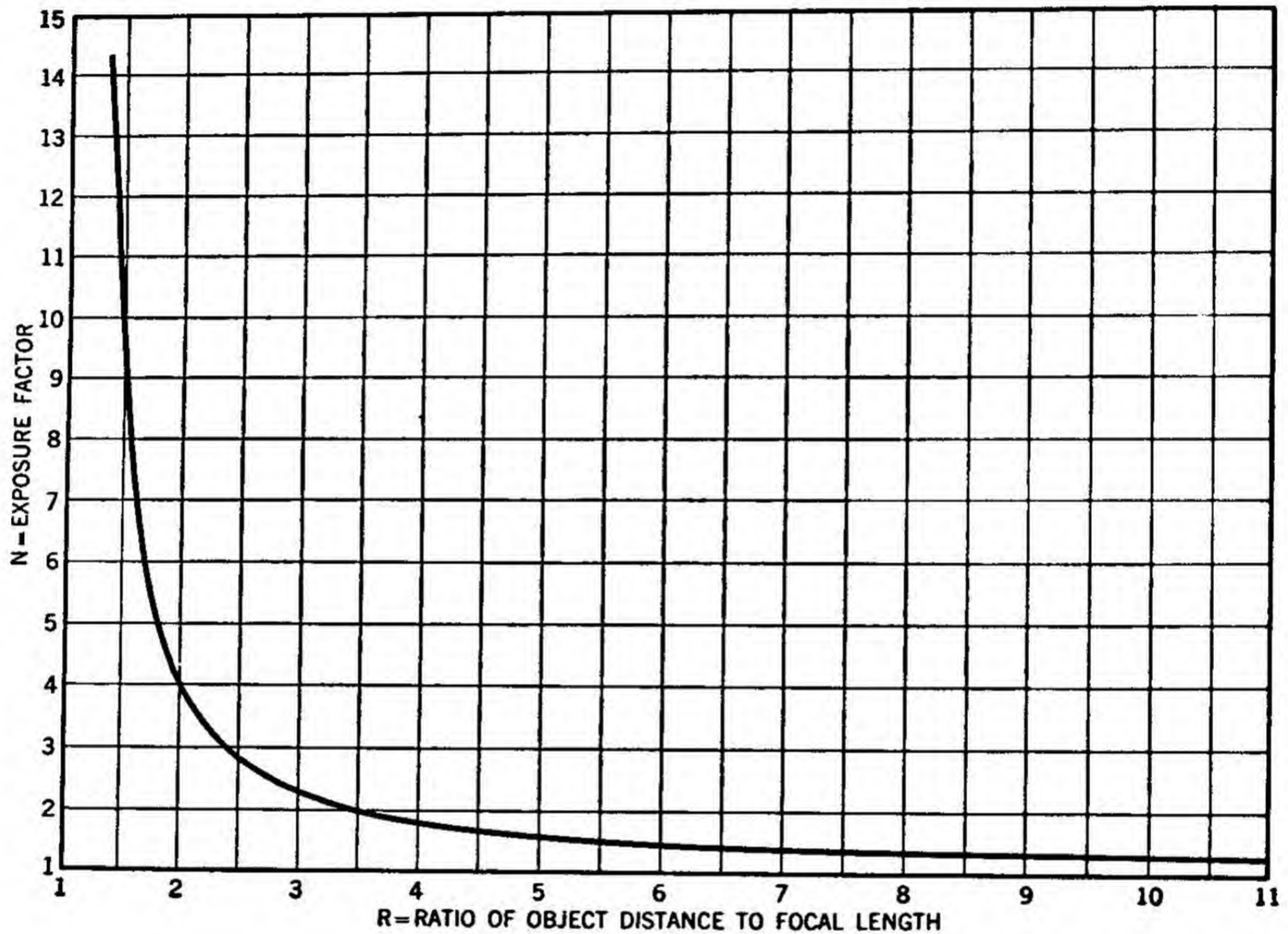


Fig. 112.

Figure 113 represents the characteristic curves of a series of papers. In each case the development has been carried to gamma infinity. Further increase in development would merely shift the curve parallel to itself along the log exposure axis. These curves differ in contrast and scale. The latitude of a paper is the ratio of the exposures corresponding to the end points *B* and *C* of the straight-line section of the characteristic curve as in Fig. 109. Because of the small latitude of papers, it is found more practical to print a paper so that the toe and shoulder of the curve are used. Such a print is called a *full-scale* print. The *scale* of a paper is the ratio of exposures at the toe and shoulder of the curve,  $OQ/OM$  (in exposure units) in Fig. 109.

We have previously seen that the latitude of a print is much less than the latitude of a negative, chiefly because of the limits set upon the extreme tones by the nature of the paper. Glossy paper, reflecting 2 per cent of incident light in its deepest black, has a scale of 1 to 50; semimatte, reflecting 7 per cent in its deepest black, has a scale of 1 to 25; matte papers have a scale of 1 to 15.



## 15. CHOOSING A PAPER

In Fig. 113 it is seen that the latitude of a paper diminishes with increasing contrast. In choosing a paper for a negative, the scale of the tones in the negative must be considered. Faithful tone production (gamma-product of unity) may become a secondary consideration to matching as far as possible the range of tones in the negative. In ordinary reproduction work the negative should be developed to that degree of contrast which is suited to printing on a long scale or soft (No. 0 or 1) paper. In this manner a full-scale print is achieved with little distortion of tones, because the long-scale paper possesses a characteristic curve in which the slope of the toe and shoulder more nearly approach the slope of the straight-line portion than in the case of the short-scale or hard (No. 4 or 5) paper.

In practice it will be found that it is ordinarily impossible to match the exposure scale of the negative with the exposure scale of the positive. This is the

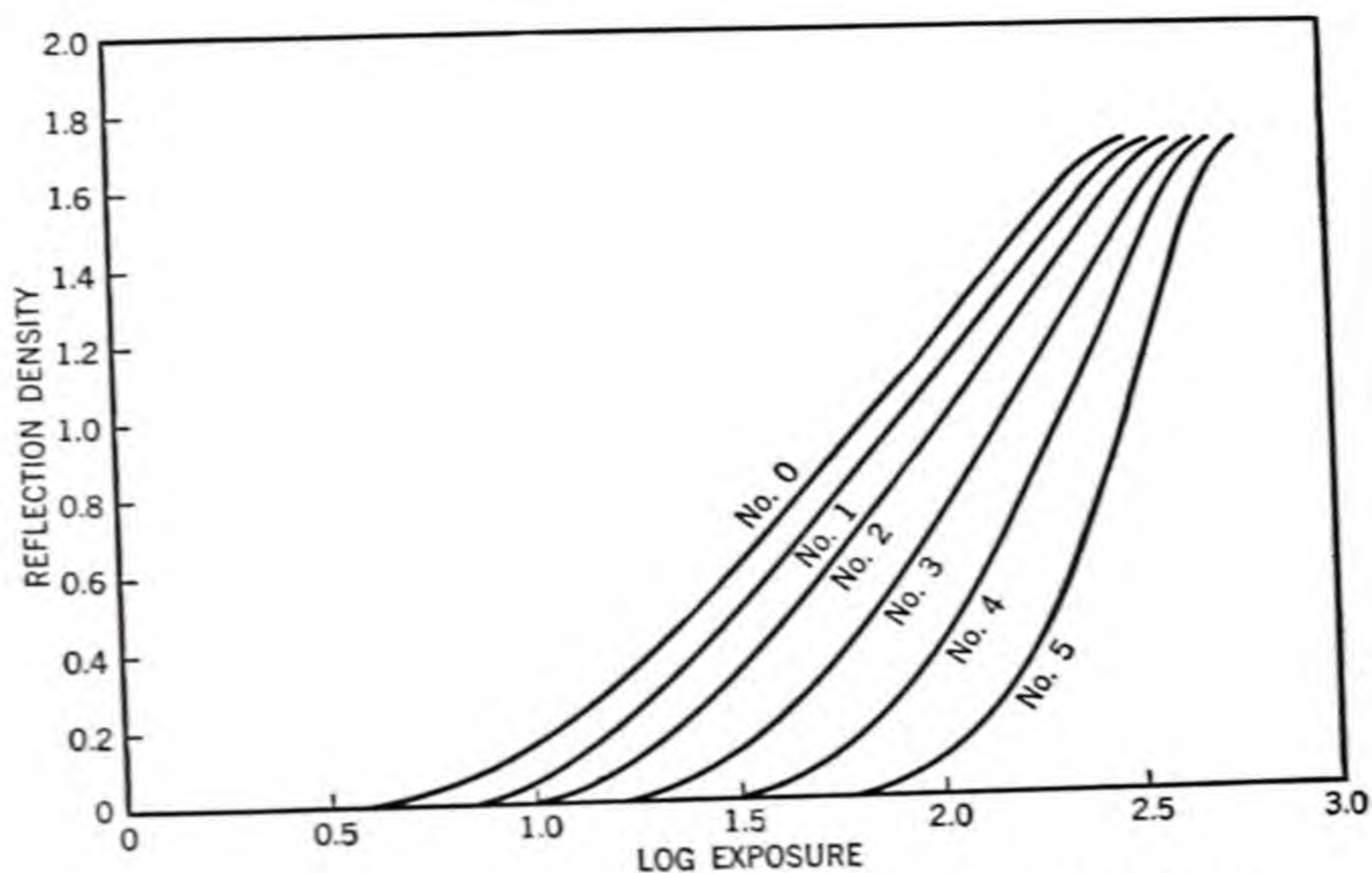


Fig. 113. Characteristic curves of a series of graded papers.

fundamental difficulty of printing. The negative must be fitted into the scale of the positive. If the negative possesses an exposure scale of 1 to 100 and the print is capable of only 1 to 30, obviously some sacrifice must be made. Three choices are offered: the sacrifice in tonal differentiation may be made at (1) the shoulder of the curve; i.e., the print may be printed for differentiation in the shadows leaving the highlights without discernible detail; (2) the toe of the curve; i.e., detail in the highlights and no detail in the shadows; (3) at both shoulder and toe; i.e., only the middle tones are differentiated.

This choice is not difficult to make in the work of the police laboratory, since the photographer is then ordinarily not striving to reproduce a wide range of tones, but is, rather, concentrating on the details of some area within a narrow tonal range. In printing, then, he is ready to sacrifice the tones outside this area provided that the detail with which he is concerned is differentiated



tonally. His selection of paper is made with this aim in view. Frequently it is necessary to use different papers to print different areas on the same negative. Thus all the details in which one is interested may have to be studied in a series of prints all made from the same negative but with each print emphasizing a different aspect of the whole.

The rôle of the print as a "rectifying" agent in overcoming the deficiencies of a negative is sometimes misunderstood. Some deficiencies of a negative can be relieved in the print; others cannot. A list of the qualities of the negative and a brief reference to the effect which the choice of printing paper can have on them may elucidate this subject.

### **Underexposure and Overexposure**

There is nothing which a print can do towards remedying these deficiencies. Such a negative suffers from a compression of tones at one end of the characteristic curve. The print cannot expand these tones — the result will not be the same as if the exposure had lain on the straight-line section of the negative characteristic curve.

### **Underdevelopment and Overdevelopment**

These defects are simply undesirable gamma values of the negative, but we have seen that the gamma-product is the ultimate determinant of the tone scale. Hence, we can remedy these defects somewhat by selecting a paper the gamma of which will, when multiplied by the gamma of the negative, give more nearly the desired gamma-product. If the negative is overdeveloped, its gamma may be 1.7. A No. 0 paper, with a gamma of, let us say, 0.8 will give a resulting gamma-product of 1.4. A greatly underdeveloped negative may have a gamma of 0.5. A No. 5 paper the gamma of which is about 2.0 will give a gamma-product of unity.

### **Constant Exposure and Varied Development.**

If we give six negatives the same exposure in photographing a subject and then develop them for different times, the choice of grade of paper for a technically correct print (gamma-product of unity) would be given by the following table:

<i>Condition of Negative</i>	<i>Number of Paper</i>
Badly underdeveloped	5
Underdeveloped	4
Slightly underdeveloped	3
Correctly developed	2
Overdeveloped	1
Badly overdeveloped	0

### **Varying Exposures and Constant Development**

If we give the six negatives different exposures within the latitude of the film, i.e., remaining on the straight line of the characteristic curve, and develop



for the same length of time, the resulting negatives will have the same contrast but will differ in density. The same grade of paper would be used for all six negatives. Different exposures would be used in printing the negatives. The resulting prints will be similar in appearance.

## 16. EXAMINING THE NEGATIVE

Before selecting a printing paper a careful visual examination of the negative should be made. Detail in shadows and highlights should be noticed as a sign of under- or overexposure. The most common error made in estimating the quality of a negative is to confuse wide density range with overdevelopment and to conclude that the No. 1 paper should be used. This is a serious error, any great degree of contrast. The deceptive wide range of brightness values in the to the middle tones, which may in fact be be a lack of contrast which could be greatly

## 17. EXPOSURE TIME OF PRINTS

### Correct Exposure

The usual advice given for exposing a print is the following: "Select that exposure time which will bring up detail from the highlight or densest part of the negative." Unfortunately this pithy recommendation is wholly inadequate except for a short-scale negative. The exposure time of a print is affected by the problem previously stated: the exposure scale of the negative is greater than that of the positive. A selection must be made of the range of tones in the negative which are to be correctly printed in the positive. For example, if the highlights of the negative are unimportant, then a middle or upper-middle tone of the negative is made the highlight of the print and the printing time is selected in accordance with the principle quoted above. If the shadows of the negative are the most important part of the photograph, and a No. 4 or 5 paper is selected to increase contrast, then, because of the short scale of the paper, the lower-middle tone of the negative is selected as the highlight of the print, and the exposure is made accordingly (Fig. 114).

In contact prints experience or test strips will usually give the correct exposure without difficulty. In enlargements photometric devices may be used to determine exposure and grade of paper, but reliance is again usually placed upon experience and test strips for a final, satisfactory print.

### Underexposure

The image is slow to appear in this case. Detail is lacking in the shadows. The proper densities are not achieved in the shadows. Prolonged development will not remedy this defect, since it cannot compensate for the unaffected silver.



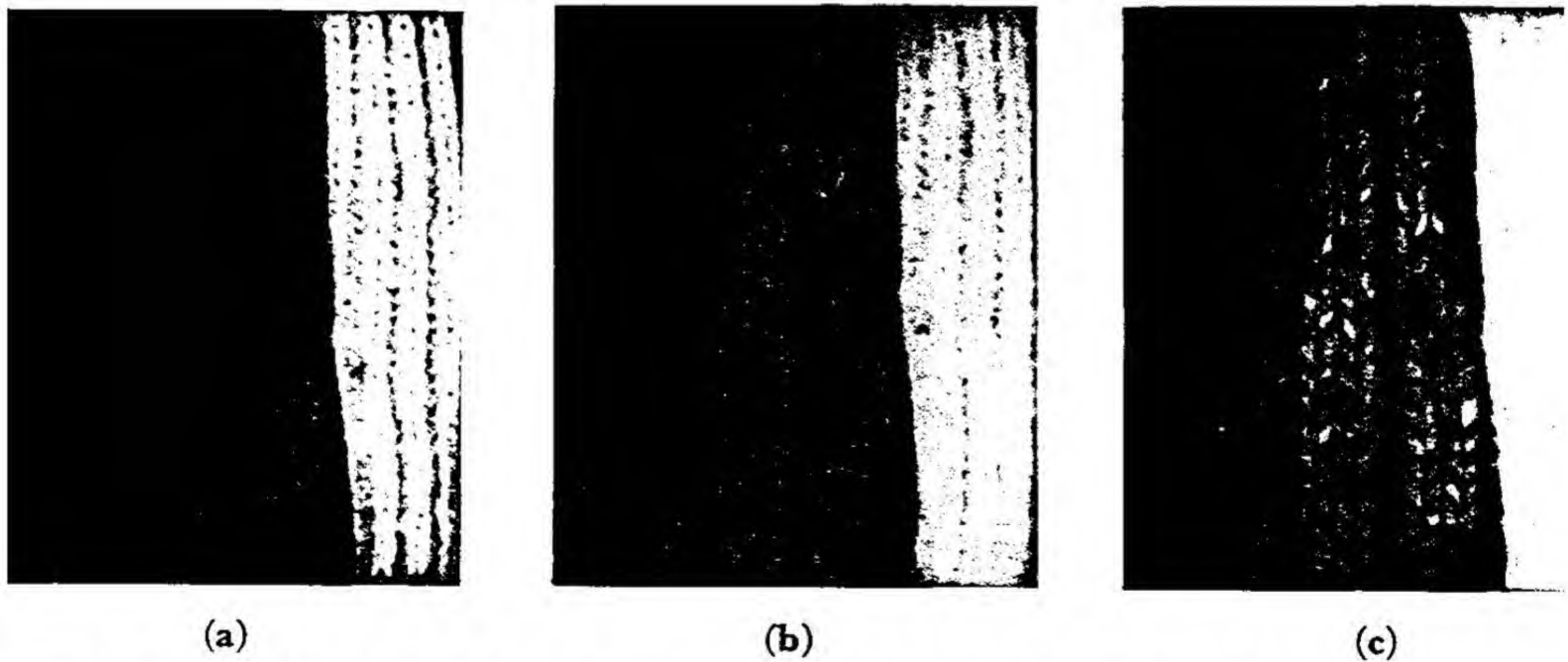
**Overexposure**

The image appears too rapidly, soon passes the point of proper development, and begins to darken all over. This excessive shortening of development time leads to a lack of control of development.

**18. DEVELOPMENT**

Prints are always developed to gamma infinity. When detail in the highlights has appeared and the blackest area of the print is a black satisfactorily comparable to the original, the print should be removed from the developer. Prolonged development will not increase the contrast but will increase only the density. Excessive development leads also to a uniform darkening of the print due to action on the silver grains which have been unaffected by light. This graying action is detectable on the border of the print, which has been masked from the light.

For best results, the manufacturer's directions for timing should be used. If the paper is to be developed at 70 F for one minute, use test strips on the Kodak Projection Print Scale, and expose the paper for an interval of one minute. The sector which looks best after one minute's development, etc., should be used in printing the picture.



**Fig. 114. Printing for different tones using the same negative and grade of paper: (a) white; (b) grey; (c) black.**

**EXERCISES**

1. As a subject of a photograph select an outdoor view which includes deep shadows as well as objects in direct sunlight. Determine the correct exposure for the scene. Take three negatives at this correct exposure. By using the meter on the shadows only, determine an exposure time which would yield an underexposed negative. Take three negatives at this exposure. Take three more negatives at an exposure time which will yield an overexposed negative, being guided by the meter reading on the brightest areas. If the film used has a wide latitude, expose for a time greatly below or in excess of the meter reading for the latter two groups of negatives.



Select one negative from each of the three groups. Develop these three negatives for average contrast. Make another selection of three and underdevelop considerably. With the last three overdevelop.

Print the nine negatives on the same grade of paper (normal) and arrange them as shown in Table 4 (see Fig. 110).

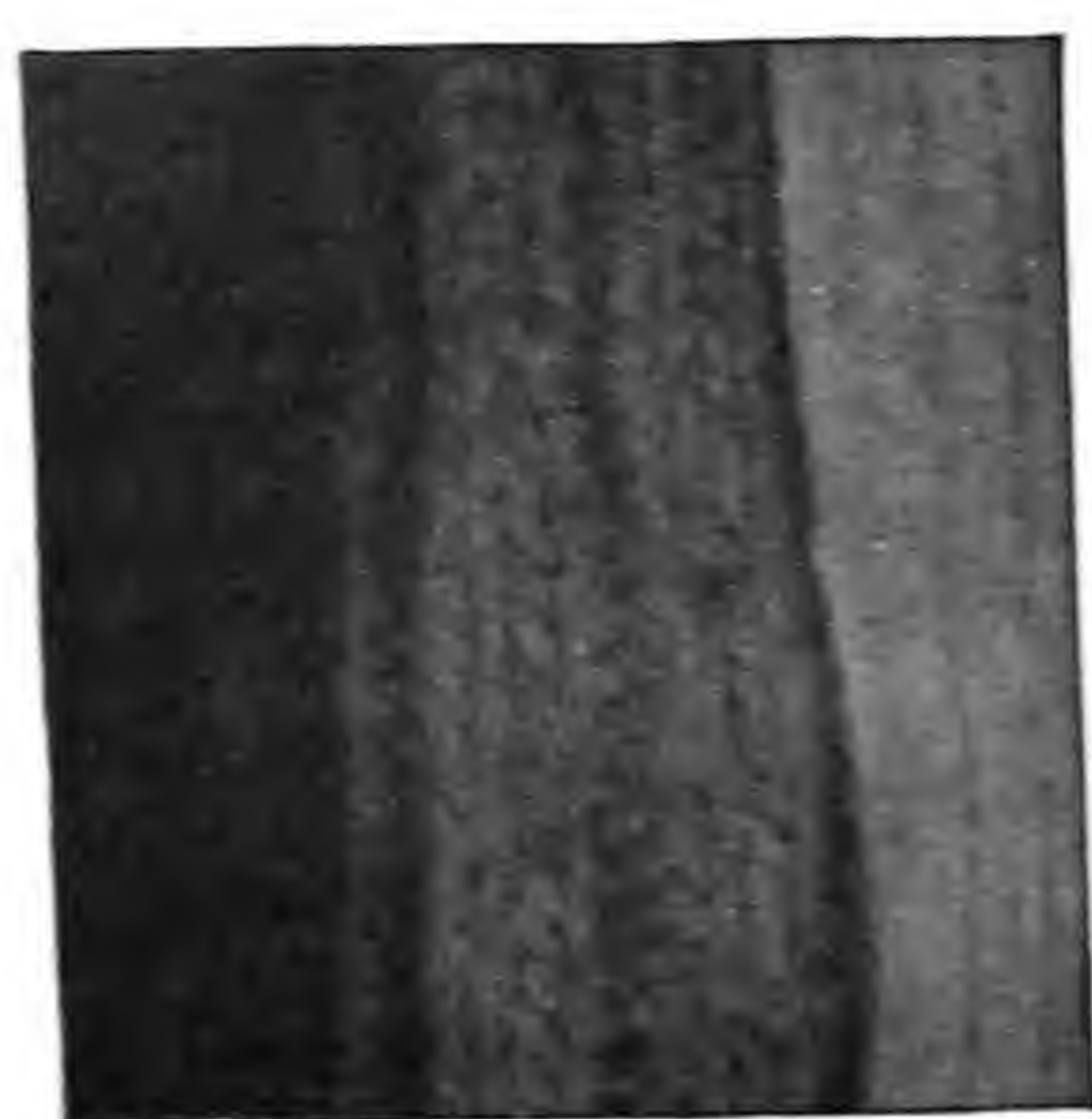
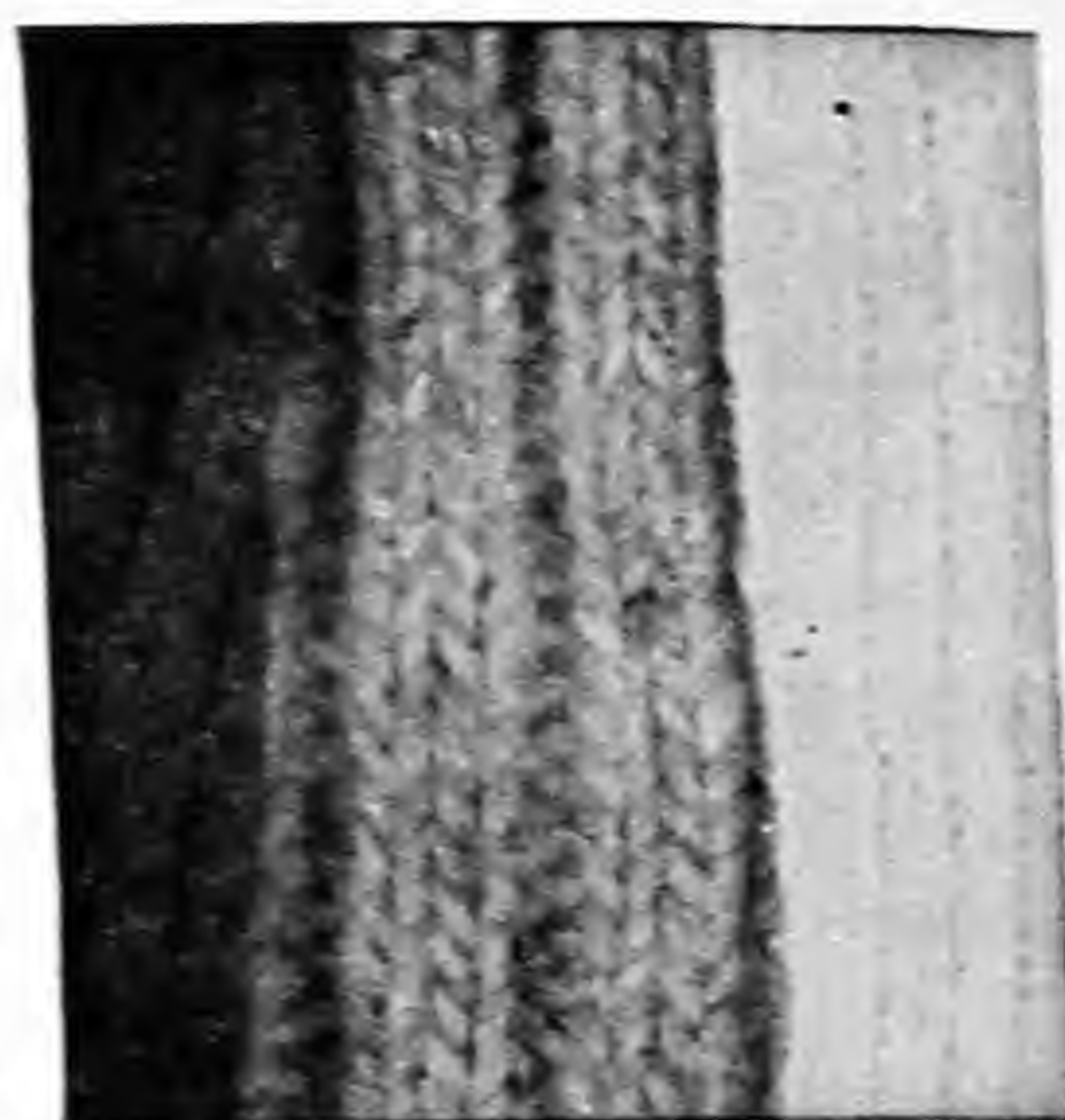
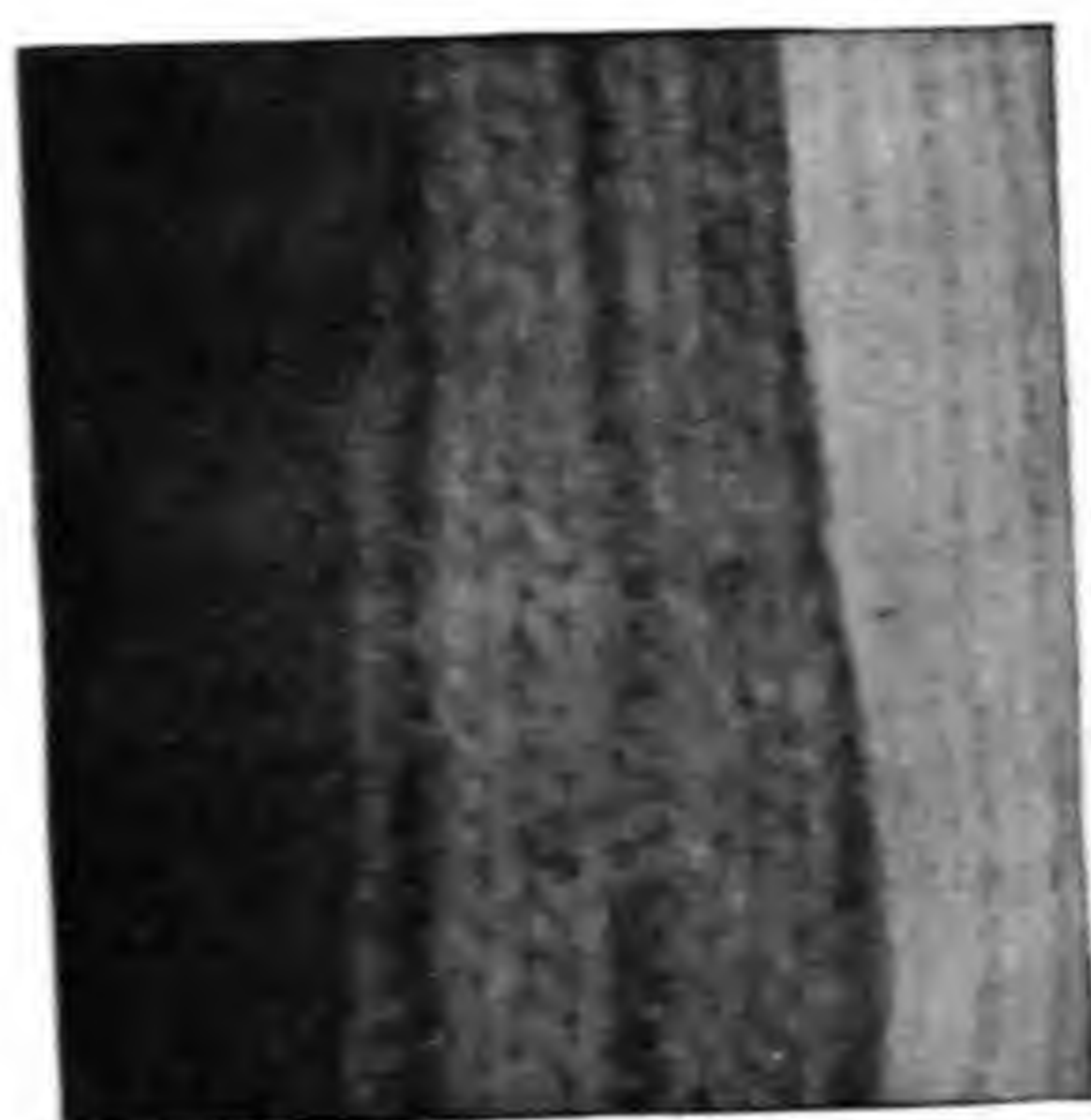
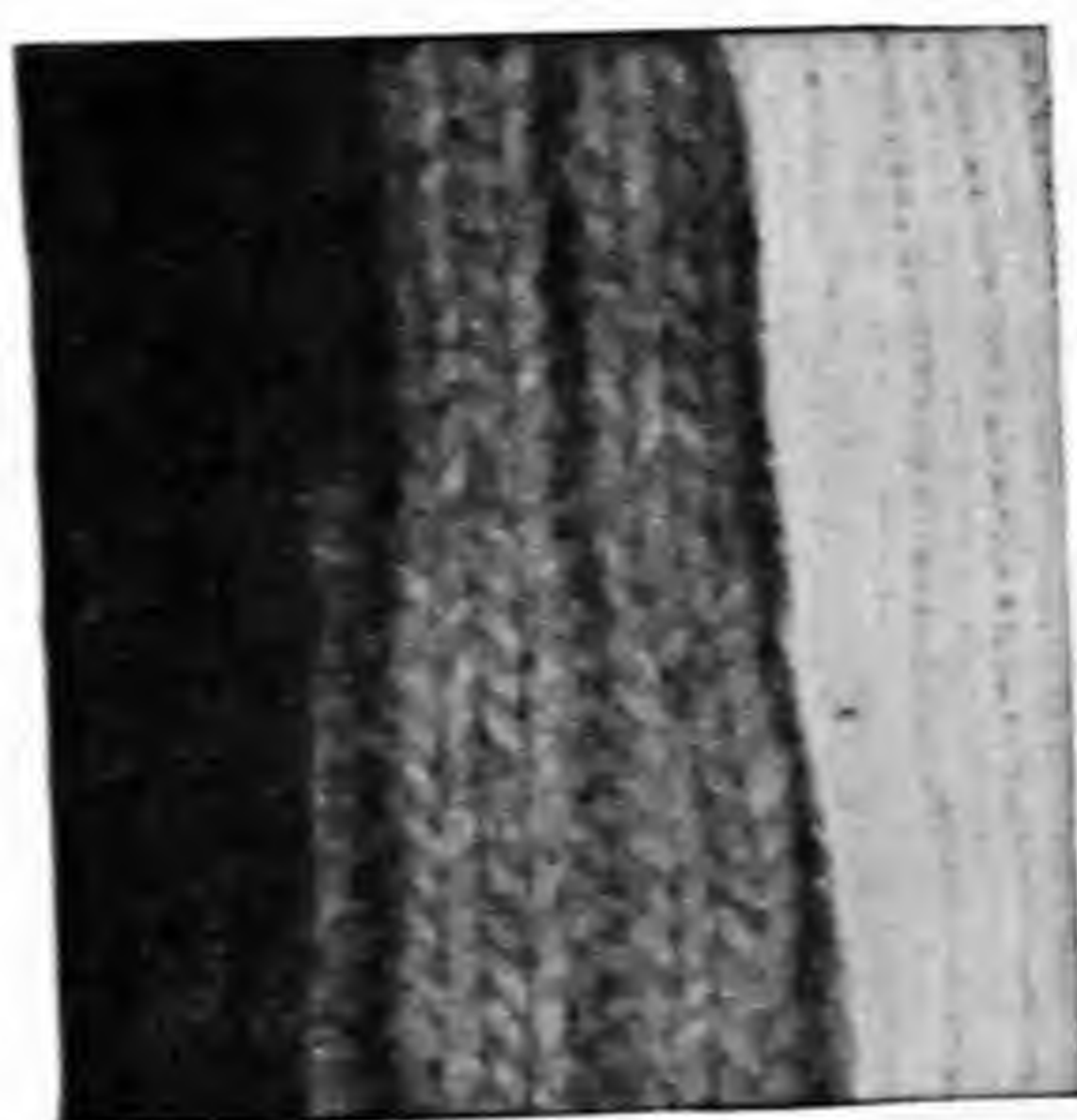
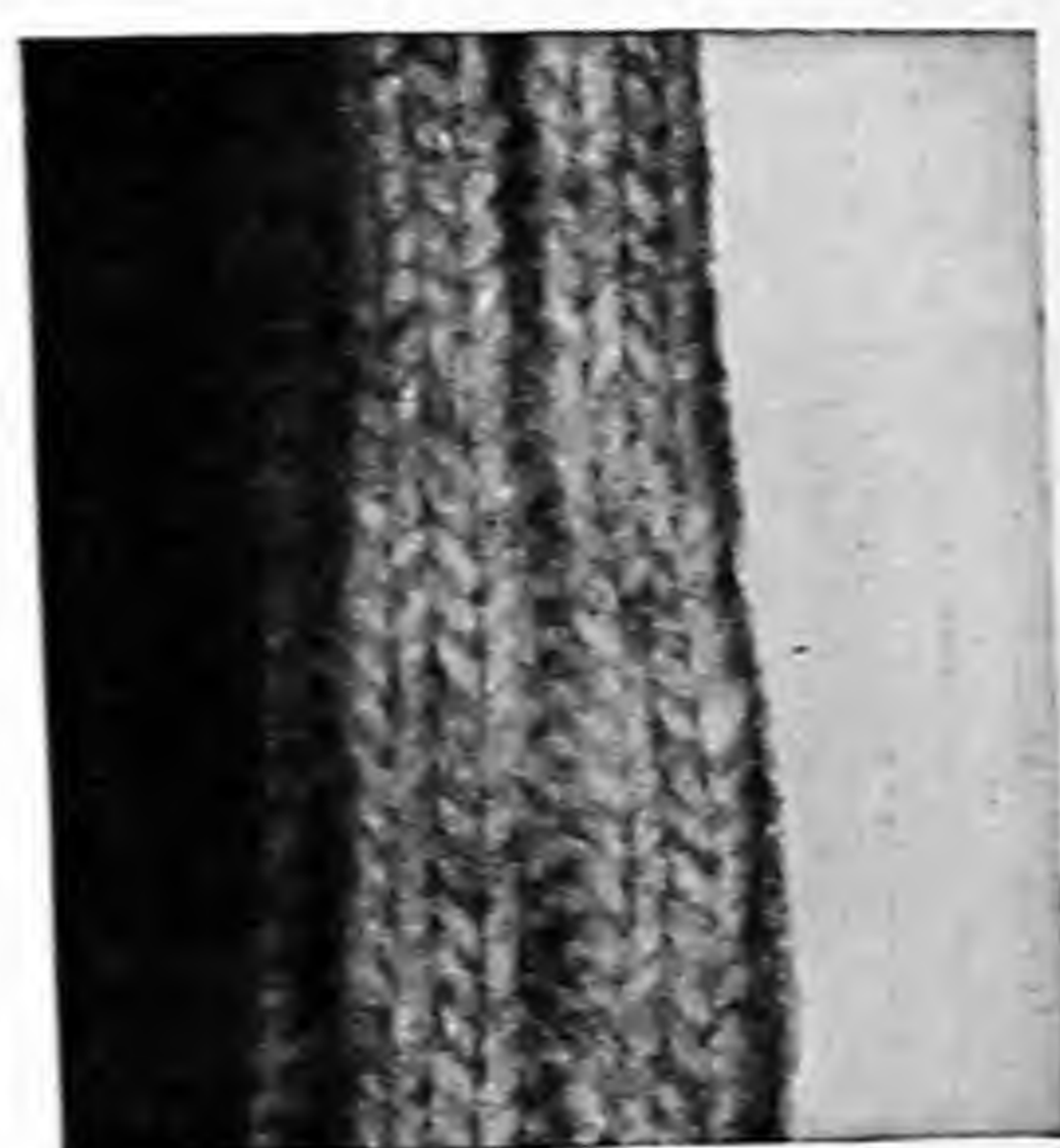
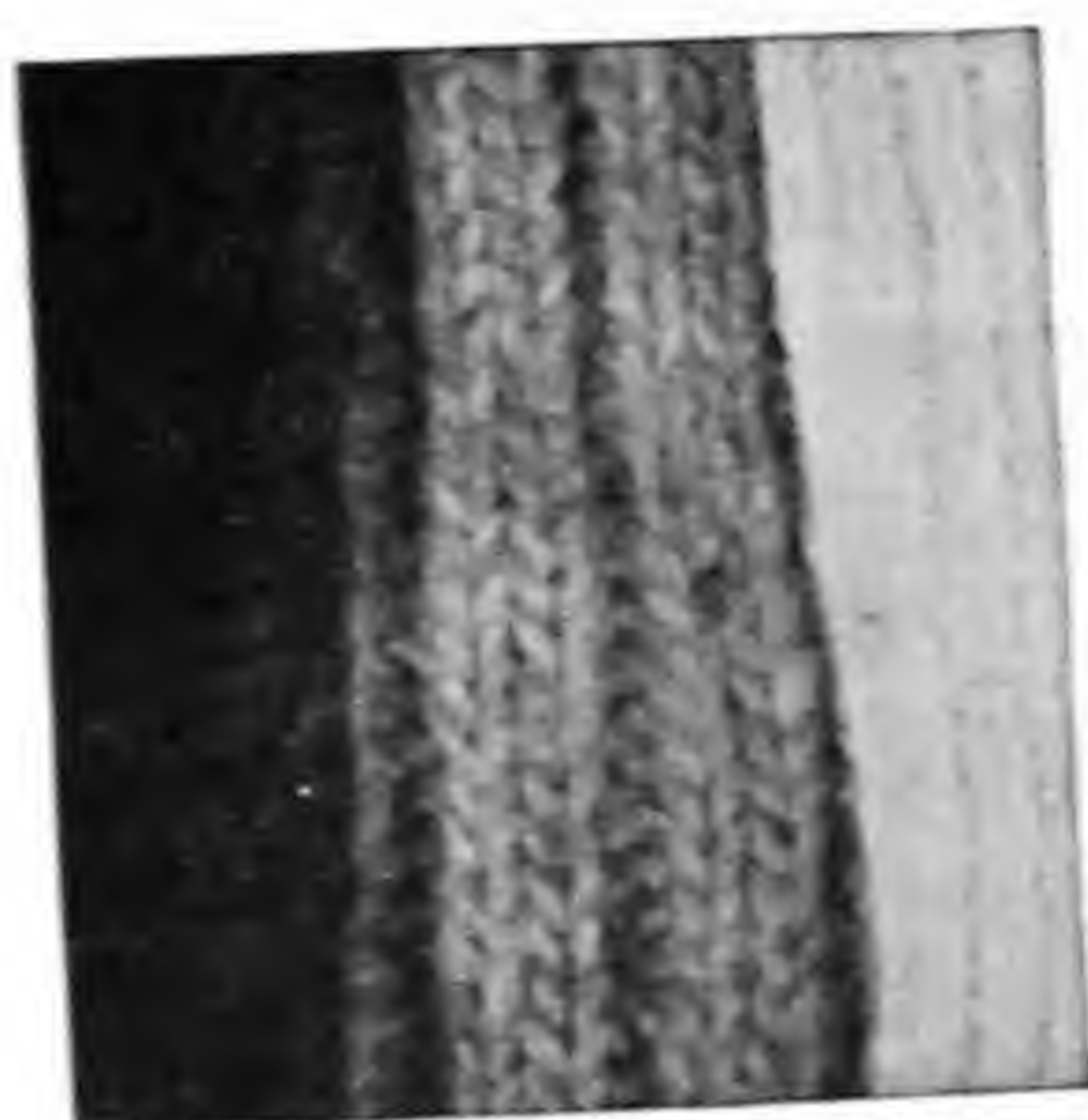
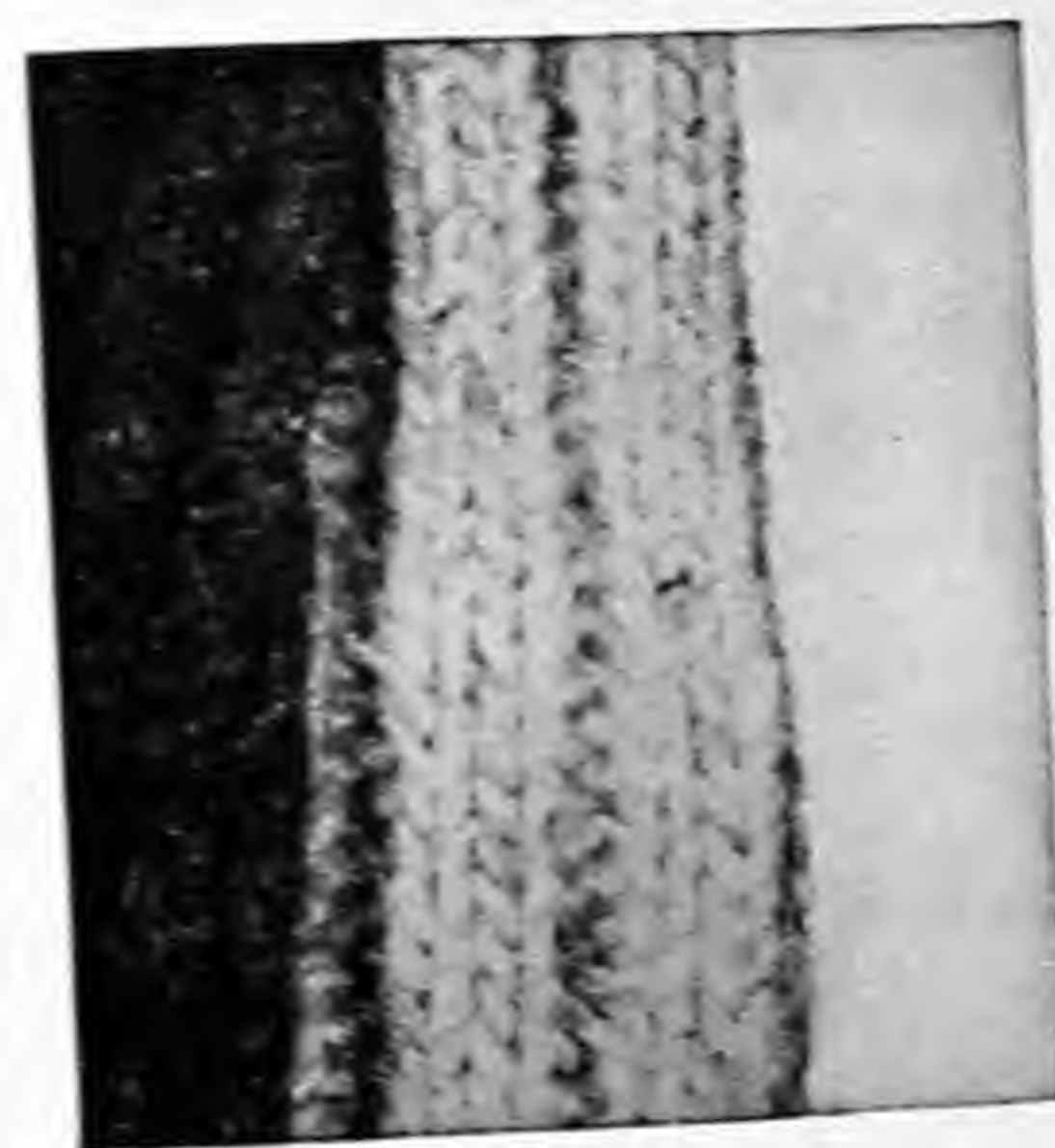
 $(a_0)$  $(b_0)$  $(c_0)$  $(a_2)$  $(b_2)$  $(c_2)$  $(a_5)$  $(b_5)$  $(c_5)$ 

Fig. 115. Nine prints from three negatives which have been normally exposed but given different degrees of development and printed on papers of three different grades of contrast. See Table 5.



TABLE 4

	UNDERDEVELOPED	CORRECTLY DEVELOPED	OVERDEVELOPED
Overexposed	d	e	f
Correctly Exposed	a	b	c
Underexposed	g	h	i

Examine the prints for the following qualities: Prints in the same column will differ in respect to the degree in which detail is represented in the shadows and highlights. Prints in the same row will differ in the degree of contrast achieved between light and dark areas. Note the failure to increase detail in the rows. Print *b* will, of course, be the correct print (since we have not given ourselves a choice of paper).

2. If the meter reading of the subject is 2 sec, and the bellows extension of the camera (10 in. focal length) is 16 in., what is the correct exposure time?

3. Select the negatives *a*, *b*, and *c* of exercise 1. Using papers of three different contrasts such as No. 0, No. 2, and No. 5, print each of these negatives. Classify the prints as follows: (see Fig. 115)

TABLE 5

	FLAT NEGATIVE	NORMAL NEGATIVE	HARD NEGATIVE
No. 0	$a_0$	$b_0$	$c_0$
No. 2	$a_2$	$b_2$	$c_2$
No. 5	$a_5$	$b_5$	$c_5$

In this table the terms *flat*, *normal*, and *hard* are used to refer to under, correct, and overdevelopment, respectively. Prints lying on the diagonal will more nearly approach normal contrast. Prints in the corner above the diagonal will be low in contrast. Those below the diagonal will be high in contrast. Compare the prints for range of tones.

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# CHAPTER 14

## THE CHEMISTRY OF PHOTOGRAPHY

Before the process of development can be understood, it is necessary to have a knowledge of the composition of film and paper materials which are employed in photography. Briefly, therefore, photographic materials contain light-sensitive substances, such as silver halide compounds, which are dispersed in a gelatin medium. This medium is called the emulsion. It is deposited on a transparent celluloid or glass base for negative material and on a paper base for positive printing material.

By exposure of the emulsion to small amounts of light, a change occurs in the silver halide and a latent image results. This latent image is rendered visible by the action of certain substances — called *developers* — on the exposed silver halide. The remaining unexposed (and hence unaffected) silver halide is removed by being dissolved in sodium thiosulfate (hypo) which, fortunately, does not dissolve free silver. The various chemicals used in developing and fixing are removed by washing in water, otherwise chemical stains appear in time. The following treatment will assume that the reader is acquainted with these routine processes, and will aim at an understanding of the basis for their use.

### 1. THE DEVELOPMENT PROCESS

Since contrasty developers are frequently employed in forensic photography, it would be profitable to examine one of these in detail. By studying such a developer it will be possible to deduce some general conclusions concerning developers and the function of the various chemicals used in them.

A formula for a developer suitable for work in a criminalistics laboratory is as follows:

Water (about 52 C)	250 ml
Metol*	1.6 g
Sodium sulfite (desiccated)	23.0 g
Hydroquinone	6.0 g
Sodium carbonate (desiccated)	34.0 g
Potassium bromide	1.0 g
Water to make	500 ml

\* This organic compound is referred to in developer formulas by various other names such as "Pictol," "Elon," "Graphol," "Photol," etc.



For paper development, add 2 parts of water to 1 part of the developer solution described above. Develop paper prints about 45 seconds at 70 F.

The following experiments may be performed in the darkroom using amber-colored lights or in the chemical laboratory if the shades are drawn and red or amber lamps are substituted for the ordinary lights. Contact paper such as No. 2 (for normal negatives) should be employed as the source of the light-sensitive silver salt. The correct exposure time should be determined for this paper and the negative printed, using the developer described above. This printing time should then be used in connection with the same negative throughout the experiments whenever an exposed print is called for. A suitable negative such as a country house with sky, lawn, and trees should be chosen so that there is a good gradation and wide variation in the tones of the subject being printed.

### EXERCISES

1. With constant stirring add 1.6 g of metol to 500 ml of warm (125 F) water. Test with litmus paper. After cooling to 65 F–70 F, immerse an exposed print and note the results.\*

2. Now add 34 g of desiccated sodium carbonate to the above solution. Test with litmus paper. Again immerse an exposed print and note the results. What conclusion may be drawn about the acidity or alkalinity required for this developer?

3. Repeat the first experiment using 6 g of hydroquinone instead of metol. Note the results and compare with those of experiment 1. Add 34 g of sodium carbonate to the hydroquinone solution and again note and compare the results.

4. In the metol, sodium carbonate solution dissolve 6 g of hydroquinone, heating the solution if necessary. Immerse an exposed print, note and compare the results.

5. Dissolve 1 g of potassium bromide in the solution just used and again develop an exposed print. What effect has this substance on the image quality — color, contrast, stains? Time required for image to develop?

6. After the remainder of this chapter has been read and the empirical results obtained above re-studied, try to predict which of the various components of a developer will be increased and which decreased in a solution that is to be used to process x-ray film (high contrast is required). Repeat predictions for a solution that is to be used in portrait photography (low contrast is usually desired). Compare your predictions with the formulas recommended by various manufacturers for x-ray film and portrait work. Do you feel that it would be advisable to attempt changing a formula to bring about some desired result or should the type of developer chosen in the first place be one that was designed by the manufacturer for your purpose?

Generally, developing solutions contain the following ingredients, the names of which indicate their function in the process.

\* All solutions, unless otherwise specified, should be used at approximately 65 F–70 F temperature. By *results* are meant such things as time required for the print first to appear, relative speeds with which highlights and shadows appear and gain in intensity, time required for complete development, presence of chemical stains, chemical fog, (i.e., unexposed parts are developed), softening effect on the gelatin of the emulsion, and, lastly, the color (black, blue, sepia) and over-all quality of the image.



## 2. DEVELOPER

Developers are usually organic substances such as hydroquinone, metol, amidol, pyrogalllic acid, etc. Chemically, they are agents which are able to convert light-struck silver halide to free metallic silver, but at the same time are capable of being controlled, so that they will not convert, i.e., develop, the unexposed silver halide during the time of development.

Developing agents vary in ability to convert exposed silver halide to free silver. A list classifying developers according to their developing power may be easily compiled from experimental data. Of the organic compounds most frequently employed as developers, metol possesses one of the highest developing potentials. When used under adverse conditions, such as temperatures below 50° F., it requires in a fractional amount of the alkali required for hydroquinone. Therefore, a developer with a higher developing potential requires less material under such conditions.

## 3. ACCELERATOR

One of the experiments above showed that the developer (metol) when dissolved in water functions more satisfactorily when it is in an alkaline solution.

As water is usually on the acid side of the acid-base scale after a developer has been dissolved, it is generally necessary to add a compound which will render the solution alkaline. For this purpose, substances such as sodium hydroxide, sodium carbonate, and sodium tetraborate (borax) are used. These compounds vary in their abilities to energize or accelerate the developer; sodium hydroxide is the most active and is used in developing solutions where a very high contrast is desired, such as in process work. However, certain undesirable effects such as softening, swelling, and blistering of the gelatin in the emulsion may accompany the use of strong alkali. In addition, chemical fog and stains may also result from a solution which is too alkaline.

Borate accelerators generally are employed in fine-grain developers and with developers of high developing potential which consequently do not require the most active accelerator in order to function. Insufficient alkalinity of the developer solution, however, results in slow development and an incomplete or weak image.

## 4. RESTRAINER

It should have been observed during the course of the experiments that a general darkening or fogging of the whole sheet of photographic paper occurred until potassium bromide was added to the solution. As the name implies, a restrainer functions in such a way as to permit the developer to convert the exposed silver bromide but at the same time to restrain the developer from converting the unexposed areas. The darkening or fogging found when insufficient or no restrainer is present in the solution, results from the developer



indiscriminately converting all the silver halide to free silver, instead of acting only upon those portions which have been exposed.

In addition, there are other defects which may result from an insufficient quantity of restrainer — reduced contrast, image development occurring too rapidly and only near the surface of the emulsion, staining of the emulsion, the color or tone of a print takes on a bluish cast varying from the usual black and white.

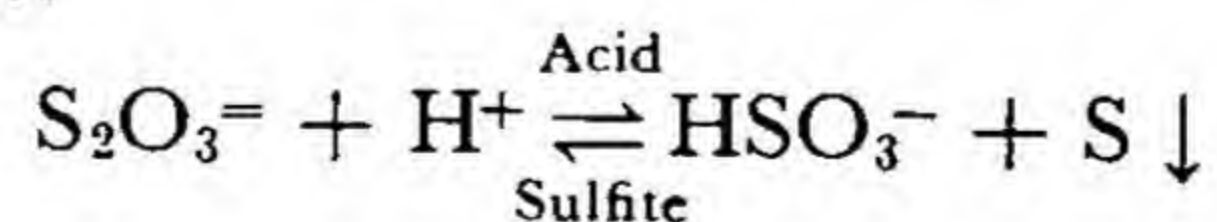
Sometimes developer formulas call for substances such as potassium iodide or sodium chloride to be used as a restrainer instead of, or in combination with, potassium bromide.

## 5. PRESERVATIVE

It is necessary to protect developer solution from oxidation by the oxygen of the air. Sodium sulfite is usually added to the solution for this purpose. Oxygen reacts with this compound to form sodium sulfate instead of reacting with the developer to form colored oxidation products which tend to stain the emulsion. In addition, the softening effect of the accelerator on the emulsion is lessened by the preservative.

## 6. FIXATION

After the latent image has been developed to the desired gamma, it is necessary to stop development at this point. The remaining unexposed silver halide must also be removed before the photographic material may be examined in daylight. Finally, the emulsion which has been softened by the developer solution must be hardened. These requirements may be satisfied by the use of a separate solution for each purpose, but usually all three are fulfilled at the same time by employing an all-purpose solution known as an acid hardening fixing bath which has had a preservative added. Usually, the fixing bath contains acetic acid to stop development, sodium thiosulfate, which is commonly known as *hypo*, to dissolve the undeveloped silver halide, and an emulsion hardener such as potassium alum or formalin. In addition a preservative such as sodium sulfite or bisulfite is added to the fixing solution. As in developer solutions, the preservative is added to prevent emulsion stains arising from the oxidation products of the developer which in this case are carried over in the emulsion from the developer solution. The preservative also serves to prevent decomposition of the sodium thiosulfate by the acid present, as indicated by the following ionic equation:



## 7. WASHING

Undoubtedly everyone is familiar with the discolored or faded prints frequently found in family photographic albums. These are the result of improper washing by the photographer to whom the film was entrusted for printing. In order to avoid these defects, it is necessary to recall that during the course of



development and fixation the chemicals used have penetrated the gelatin emulsions as well as the base or support for the emulsion. These chemical impurities, therefore, must be thoroughly washed out; otherwise they will affect the image by causing it to discolor or fade in time. This is especially true in forensic photography where photographic evidence may be called upon later in connection with a related investigation, or where the case is carried to a higher court on appeal. Where the evidence in question is perishable with the passage of time (e.g., fingerprints developed by iodine or indented writing developed by oblique lighting techniques), it is obviously very important that proper care be exercised in the entire photographic process, and particularly in the washing of the negative.

It can readily be demonstrated that negative materials are easier to wash than prints because of the paper fibers which tend to retain the undesirable chemicals. For this reason double weight paper is required to be washed more than single weight. The working directions for photographic materials usually contain information relative to the method and time of washing. These instructions should be followed carefully and any time specified for washing should be regarded as a minimum.

## 8. GENERAL

The directions for processing photographic materials have been carefully worked out by manufacturers for their photographic supplies and should be faithfully followed. Developing solutions should not be altered by adding to or subtracting from the quantities of chemicals called for in order to attempt to bring about some desired result, such as increased contrast. Rather a developer should be used which was originally designed to bring about the desired result. The directions for preparing developing solutions should be closely followed, mixing the chemicals in the manner specified; otherwise undesirable results may follow. For example, if the alkali and developer are added without any preservative present, the oxidation products of the developer will probably stain the emulsion.

Careful fixation and washing of negatives and prints will insure the permanence of the silver image without the danger of stains appearing in time.

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# CHAPTER 15

## *COLOR PROBLEMS AND THE USE OF FILMS, FILTERS, AND POLARIZING SCREENS*

### **1. REPRESENTING COLORS IN BLACK-AND-WHITE PHOTOGRAPHY**

In discussing the photography of color we shall be interested in the problem of the representation of colors as tones in the black-and-white scale. Photography by means of color film is, of course, the ideal solution to the problem of color representation. The progress recently made in this field will no doubt make possible home processing of color film and thus permit its widespread use in criminological work. At present, however, the police photographer must rely mainly on non-color film.

The subject of color in the black-and-white tone scale will be treated from two points of view: first, the problem of the "correct" rendering of color in the black-and-white scale in the sense that the eye will be affected by the brightness differences in the finished print in a manner similar to (or to a degree commensurate with) that in which it is affected by the brightness effects of the colors in the original subject; second, the problem of achieving maximum contrast between two or more colors in their representation in the finished prints, so that certain aspects of the subject are emphasized.

The first of these problems occurs when a "faithful" photograph is desired. In the photograph of the scene of a crime, for example, it may not be desirable to represent certain red or green objects as black. An objection may be made to such a photograph on the grounds that it is a distortion. The second problem is of greater interest to the police scientist. It can be thoroughly understood, however, only in relation to the first, since its solution follows from that of the first as a corollary. Contrast of tones in representing colors will, as we shall see, be of invaluable assistance to the investigator. The correct choice of filters and film emulsions will often make visible in the photograph details and aspects of the subject which are invisible when viewed normally. Erasures, obliterations,



and fingerprints present problems in photography which frequently must be solved in this manner.

Three elements control color rendition: the spectral sensitivity of the photographic materials, the nature of the light reaching the negative, and the spectral sensitivity of the eye.

## 2. THE NATURE OF LIGHT

If a narrow beam of white light is passed through a prism, the resulting image is a band of colored light ranging from blue to red. White light, then, is a mixture which is the sum total of all the colors in the band of light which we call the visible spectrum. On close examination of this band it will be found that

... , for example, leaves off and orange begins. The word is, in fact, a region of the spectrum the ... defined.

... better understood ... we consider ... as a portion ... energy — the e ... magnetic ... e spectrum. ... er where the v ... are arrang ... in the order ... of their length. T ... prod ... t of the wave length ... frequency ... any wave of radiant energy is always  $3 \times 10^{10}$  centimeters per second, the speed of light.

It is interesting to note how small a part of the whole spectrum is included in the visible region. In the terminology of sound, the eye covers only one octave. The human ear has a range of about ten octaves; i.e., the longest sound waves perceptible are 1000 times as long as the shortest waves. The eye, however, is sensitive in a region where the red or longest waves are only twice as long as the violet or shortest waves. Flanking both sides of this spectrum are light waves which do not affect the eye. On the one side are infra-red rays, which are too long for the eye; on the other are ultraviolet rays, which are too short. Both of these types of radiation do, however, affect certain photographic emulsions and will be found to be of great value to the police scientist. The eye differs again from the ear in another important property. The ear is capable of analyzing into its components complex sounds such as that of an orchestra. The eye, however, cannot determine the spectral components of a complex stimulus such as white light or mixed colors.

## 3. COLOR SENSITIVITY OF THE EYE

To understand the reaction of the eye to the various colors of the visible spectrum we must consider so-called *pure* colors. A pure color will be considered as consisting of light of only one wave length — monochromatic light. (It should be remembered, however, that the colors encountered in practice cover a wide spectral region.) Because of the shortness of light waves, special units are needed to express their length. One unit commonly used is the Ångström or Å. The Ångström unit represents  $10^{-8}$  centimeters. The visible spectrum runs from 3900 Å, which is in the blue region, to 7800 Å, in the red region. The ultraviolet region extends to 1000 Å; the infra-red to  $3 \times 10^6$  Å or 0.03 cm.



Figure 116 is a graph illustrating the spectral sensitivity of the eye. The ordinates of this curve correspond to *relative visibility*, which is the reciprocal of the relative amount of energy producing a certain sensation of brightness. In the curve it is seen that the eye is most sensitive in the green region and its sensitivity decreases fairly uniformly on both sides. This high sensitivity in the green region is the reason why a green safelight is used in the darkroom with panchromatic film.

We consider now the first problem of the photographer in relation to the rendering of colored objects in a photograph — that of correct rendition. In making a photographic record of the scene of a crime or in a simple photographic record of evidence, the laboratory technician will desire a preservation of relative tone values of the colors proportional to the stimuli received from these colors by the eye. To do this he must select a film such that its range and sensitivity in the spectral region will be comparable to that of the eye. No film will

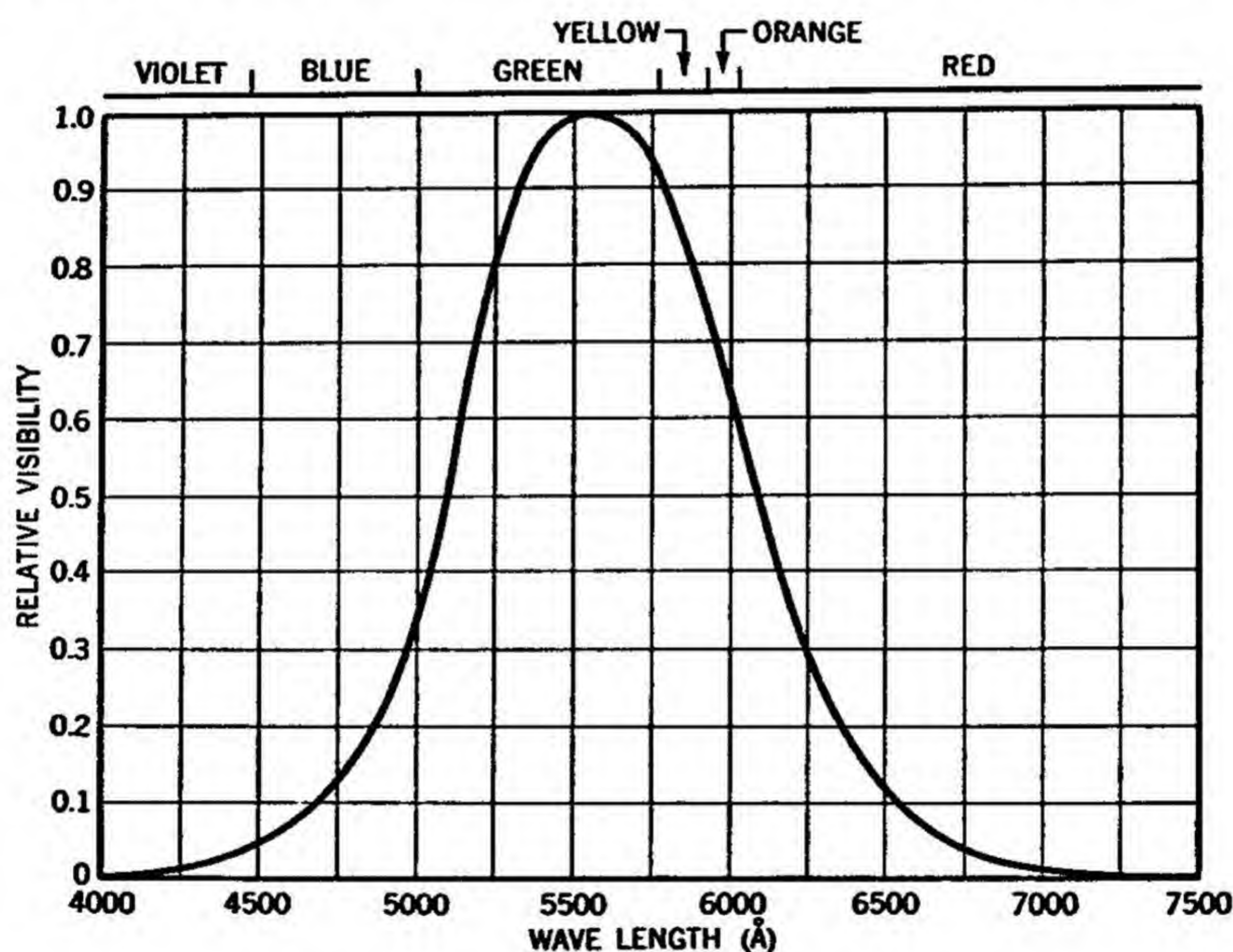


Fig. 116. Color sensitivity of the eye.

accomplish this perfectly; panchromatic films, however, most nearly approach this goal. A knowledge, then, of the color sensitivity of film materials is indispensable to the intelligent photography of colored subjects. For general use the following classification of films according to color sensitivity may be made:

#### 4. COLOR SENSITIVITY OF FILMS

*Class I* is the non-color-sensitized type which includes *process* and *commercial* films. These films are practically color blind, being sensitive, for practical purposes, only in the ultraviolet and blue-violet regions. They should not be used in photographing colored subjects when it is desired to suggest the colors by means of tones. Their use should be restricted to black-and-white subjects and



to subjects in which it is desired to render blue as a light tone or to render any other color as black. Their sensitivity in the ultraviolet region recommends their use in ultraviolet photography. In color rendition, process film is similar to orthochromatic film and panchromatic film when these are used with a blue filter.

*Class II* orthochromatic films which are predominantly sensitive in the blue and violet, moderately sensitive in yellow and green, and almost insensitive in red. *Commercial ortho*, *verichrome*, and *plenachrome* are common trade names for this type of film. Orthochromatic film may be used to render red darker but only at the risk of affecting yellow, purple, and brown. A red safelight may be used with Class I and II films.

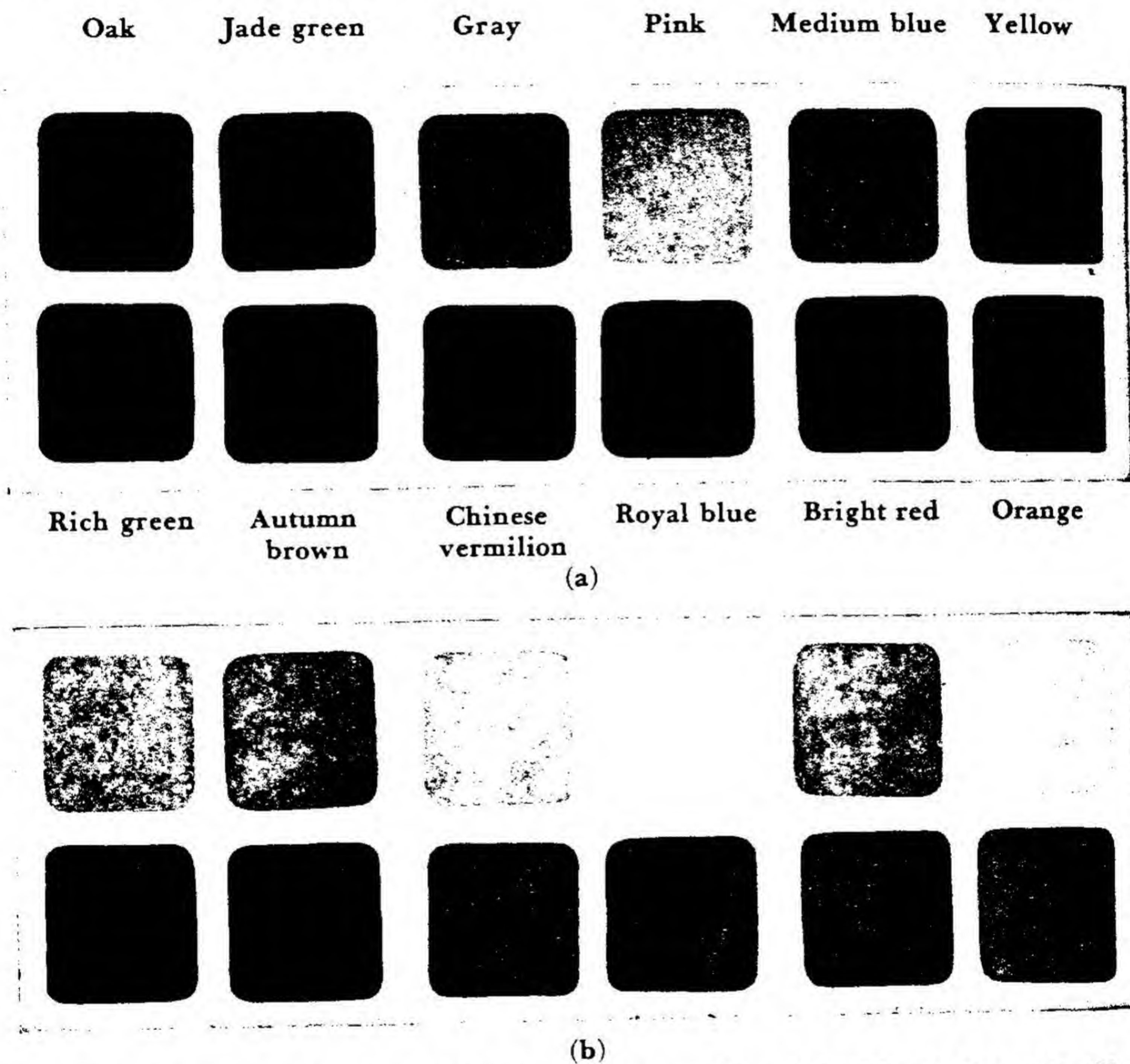


Fig. 117. Paint chips photographed (a) with process film; (b) with panchromatic film.

*Class III* films are known as panchromatic. This type is sensitive to all colors including red. Colors are reproduced as tones corresponding in intensity approximately to the intensity with which the eye would receive them. The correspondence is not complete because of the increasing sensitivity with which the eye perceives colors in the green region. It is possible by the proper use of filters with panchromatic film to reproduce colors in the same relative brightness that the eye sees.



## 5. THE PROBLEM OF CONTRAST

It has been already stated that the more important problem in the black-and-white photograph of colored objects is the introduction of contrast into the photograph. This can to some extent be accomplished by the use of film alone, since orthochromatic film yields the same results as though panchromatic film were used with a green filter, and process film gives the effect of orthochromatic or panchromatic film with a blue filter. Thus a blood-stained footprint on a green linoleum would when photographed with ortho film appear to be a black footprint on a lighter background; a black fingerprint on a blue background would in a process film photograph as a black print on a light background; a white fingerprint on a yellow background would appear as a white print on black, with process film.

The ability to achieve contrast between colors by means of film characteristics is quite limited. The usual procedure is to rely upon the use of filters. To use filters intelligently it is necessary to possess some knowledge of their action on incident light.

## 6. THE EFFECT OF FILTERS

If one looks through a blue glass, many objects appear blue. This occurs, not because the blue glass colors the light which it transmits, but because the blue glass absorbs all colors from the white light except blue. Similarly, red glass absorbs all colors other than red, thus giving most objects the appearance of red. This subtractive process of producing color by transmission through a colored medium is called *selective absorption*. The color of an object to the eye is similarly explained. When white light falls on an object painted green, most of the blue and red rays are absorbed so that only the residual green rays are reflected to the eye.

A light filter is a substance designed to absorb light selectively. One form of a filter, which is sometimes used in microscopic work, is a flat-sided vessel containing a colored solution or dye. The photographic filter is either a thin gelatin film impregnated with a dye and enclosed by two transparent glass plates, or a solid glass; the latter type is considered a superior filter.

## 7. COMPLEMENTARY COLORS

Two colors are said to be complementary if their combination results in an approximation to white light. For example, blue-green is complementary to red. A filter will absorb its complementary color. If we arbitrarily divide the visible spectrum into blue, green, and red, the following statements are approximately true:

A red filter absorbs blue and green wave lengths.

A green filter absorbs red and blue wave lengths.

A blue filter absorbs red and green wave lengths.

A more detailed division of the spectrum may be made by means of Fig. 118. In the circle each color occupies a sector of a circle. The heavy lines connect



complementary colors. A filter of a given color will absorb the color at the other

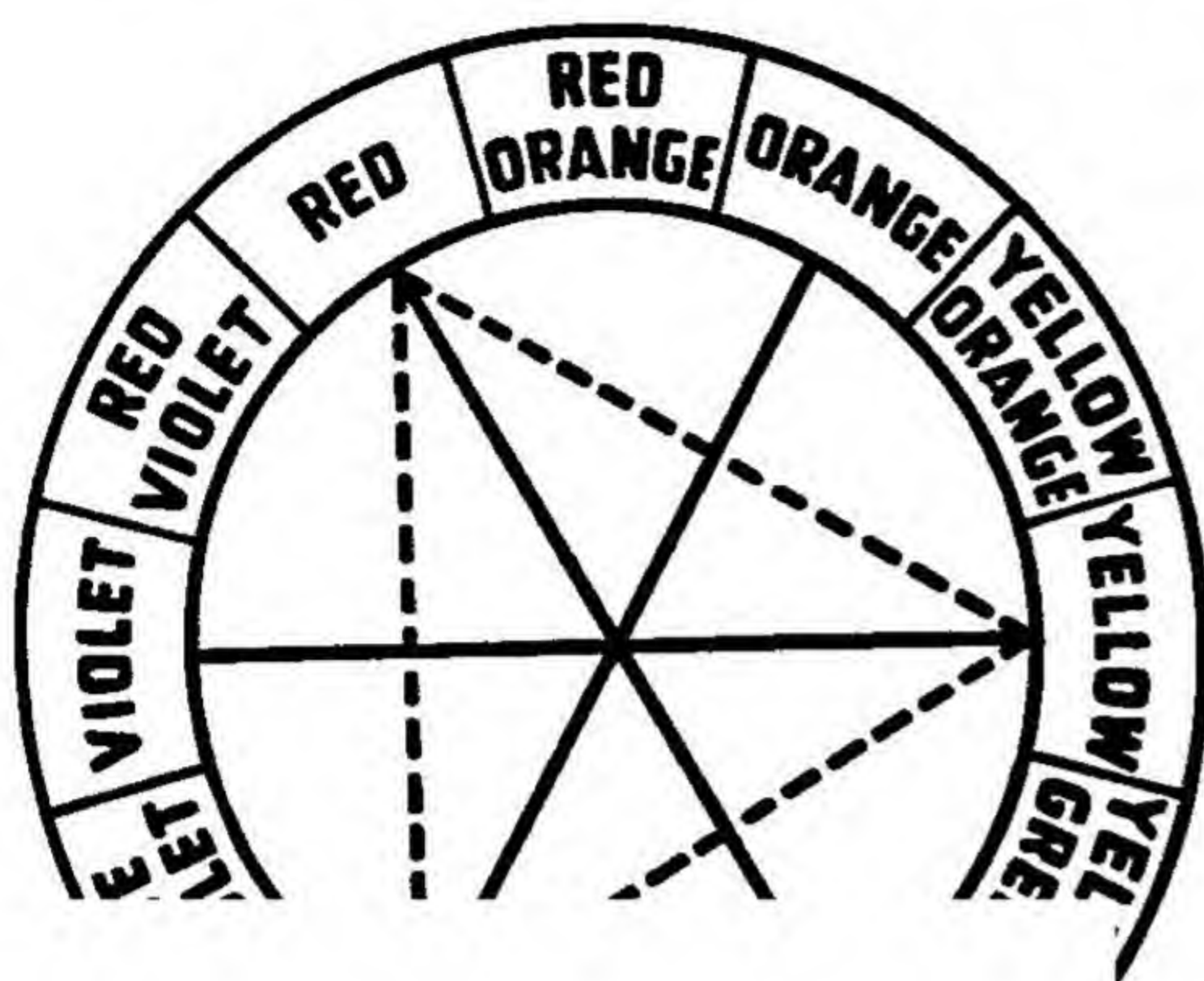


Fig. 1. Complementary colors. Complementary colors are indicated by heavy lines.

end of the heavy line and usually the adjacent colors also. For example, a yellow filter will absorb violet, blue-violet, and red-violet. This information will be found of assistance in approximating a correct choice of filter. It must be supplemented, however, by more exact knowledge of the characteristics of the filter.

## 8. FILTERS OTHER THAN CONTRAST FILTERS

Before discussing contrast filters, which is the primary purpose of this chapter, shall describe the filters which are used for other purposes so that the remainder of the chapter may be devoted to the subject of contrast.

### Correction or Orthochromatic Filters

These are designed to alter the incident light in such a manner that, in conjunction with the spectral sensitivity characteristics of the film material, the colors will be recorded with brightness values similar to those which they possess for the eye. This type of filter should be used in photographing, for example, a motor vehicle accident in daylight, where it is desired only to reproduce a faithful picture. It will be recalled that panchromatic films respond to colors differently from the eye, recording, for example, blue lighter than green. A number of filters are available for reducing this blue sensitivity so that the green is lighter than the blue, as it is in its effect on the eye.

### Miscellaneous Filters

Haze filters eliminate aerial haze in outdoor work. Tricolor filters are used in making color-separation negatives. Neutral density filters reduce exposure. They are especially useful in photomicrography.

## 9. CONTRAST FILTERS

Contrast filters are used to alter the brightness values of colors in order to enable the eye to distinguish among them. For instance, a photograph with process film of a bloodstain on a green cloth may fail to reveal any contrast. The use of a red filter and panchromatic film would enable one to distinguish the spot. Two principles should be kept in mind when contrast among colors is desired. First, to photograph a color darker than its background, use a filter



which absorbs the color. Second, to photograph a color lighter than its background, use a filter which transmits that color to the exclusion of others. In making a choice of filter, the object should be viewed through various filters and the contrast noted in each case. For example, in photographing a blueprint, a red filter would be chosen because it would permit the white lines to appear white and at the same time exclude the blue, thus giving white lines on a black background. A green filter would also be correct if the blue of the blueprint is pure blue and not blue-green.

No attempt will be made here to describe the many filters which are available to the photographer. In using a filter, the manufacturer's data should be at hand to provide the needed information. The booklet *Wratten Light Filters*, published by Eastman Kodak Company, lists a large number of filters together with their spectral sensitivity curves. (A partial list is given on p. 558.) These sensitivity curves, or wedge spectrograms, provide the only reliable criterion for a choice of filters. The general type of filter should first be chosen tentatively by inspection of the object to be photographed. The properties of the filters which belong to this class should then be studied in relation to the type of emulsion used.

In order to use contrast filters effectively, consideration must be given to both the spectral qualities of the light source, and the color of the object being photographed.

## 10. LIGHT SOURCE

The simplifying term *white light* has been used thus far to designate light sources in general. The spectral quality of the light source, however, is important. An object can transmit or reflect only the colors which are already in the light source. If the incident light is red, a blue or green object will appear black because the red is absorbed, and there is no blue or green light to be reflected. It is for this reason that the colors of materials should not be matched in artificial light. Although the spectral qualities of the lights differ but little, materials that match in color under artificial light will often fail to match in daylight. Because low-temperature light sources such as a kerosene lamp or a candle are deficient in blue light, it is impossible to distinguish dark blue from black in this light. An incandescent tungsten filament at 3000 C provides a light increasing in photographic intensity with increasing wave length. Where great difficulty is experienced in obtaining a photograph of sufficient contrast, it is worth while to photograph the object using daylight instead of artificial light and compare the results.

## 11. COLOR OF THE OBJECT

Thus far we have mentioned red backgrounds and blue objects as though these colors were found in nature in their pure state. This concept is one of the causes of serious errors in the use of filters and is a major source of photographic disappointments. Unfortunately, pure colors are rarely found in an object. A colored object ordinarily will reflect light of all wave lengths. Purple stationery



(Fig. 119), for example, will probably reflect all colors of the spectrum but will reflect most intensely in the blue region. We cannot, then, completely darken or completely lighten a background by the use of filters since the object will always be reflecting light in and outside of the region of the filter.

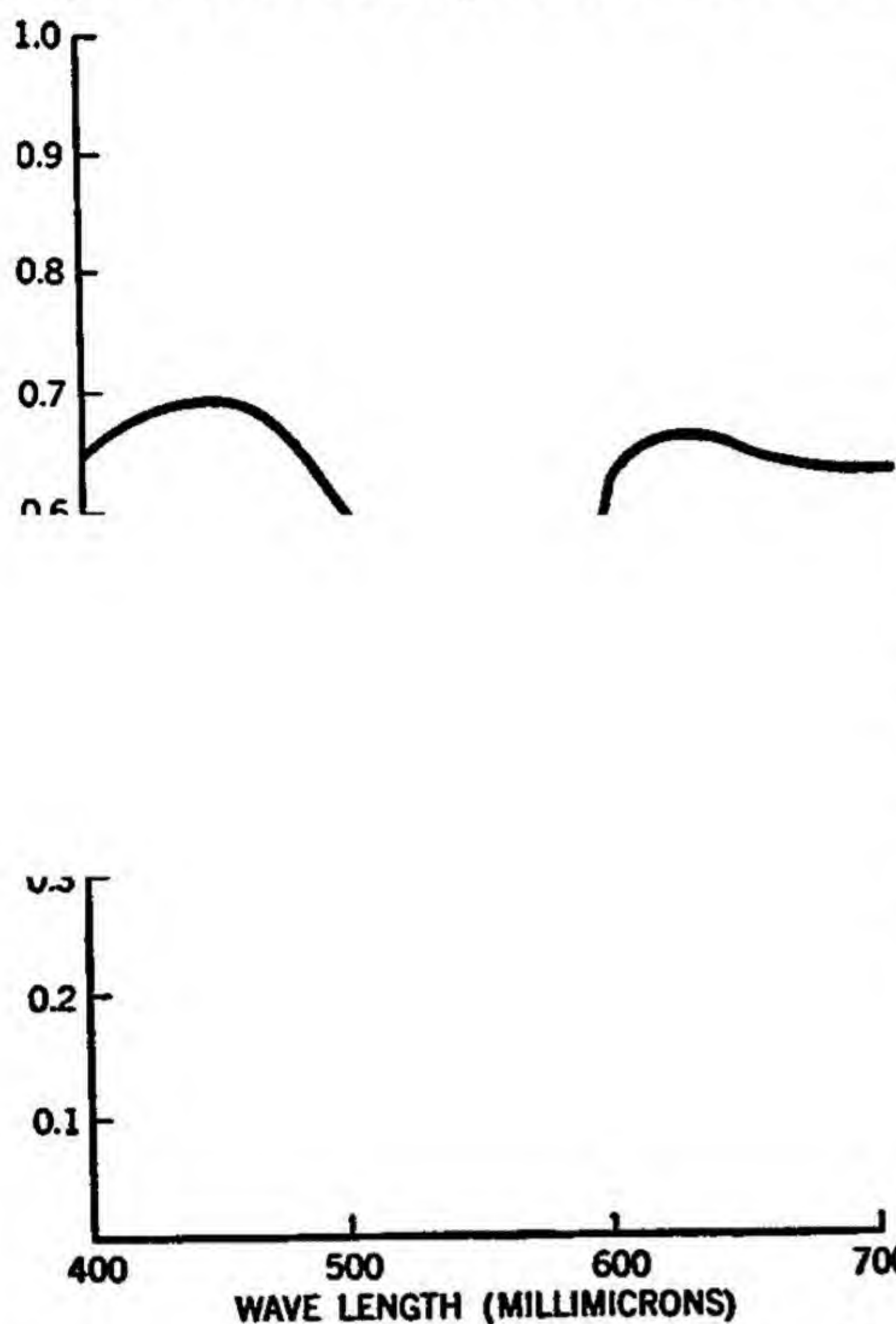


Fig. 119. Spectral reflectance curve of a violet paper.

The problem is further complicated by the fact that the color of an object varies with the direction of illumination and observation. The angle formed at the object by the illuminant, and the camera lens will affect the color characteristics of the object. It is not to be expected that the photographer should worry over these matters, since there is little that can be done to control them. It is well, however, that he have an understanding of the difficulties which confront him so that he can interpret any lack of success in the photograph.

## 12. FILTER FACTOR

In using any filter, it must be remembered that the transmitted light of all wave lengths is reduced in intensity. The exposure must consequently be increased. The amount of increase depends upon the source

of light, the nature of the emulsion, and the color characteristics of the object. The manufacturer's data include a *filter factor* by which the normal exposure time is multiplied to give the approximate time for the exposure with the filter.

In the case of infra-red film, no filter factor need be used to calculate the exposure, because the speed rating given for the film is calculated on the obvious assumption that a filter is being used. However, when deep infra-red filters are used, a factor must be taken into account.

## 13. LIMITATIONS OF FILTERS

Another source of disappointment is the fact that most common filters do not transmit light only in narrow spectral bands in the immediate regions of their dominant wave lengths. It is extremely difficult to prepare a filter which will transmit one narrow portion of the spectrum and exclude all others. Some transmission in adjacent regions is unavoidable. Certain green filters, for example, will transmit in the green and red but not in the yellow.

## 14. COMBINATIONS OF FILTERS

For special purposes, a combination of filters may be used in front of the camera lens. For example, to limit the transmission to a narrow region in the



green, it is possible to use a blue and a yellow filter together. To use filters in this manner intelligently, it is necessary to consult the absorption curves of filters in the manufacturer's literature (see also p. 556). It will be found there that in absorption curves the transmission is measured by density and plotted against wave length. The absorption curve of a combination of filters is determined by adding the ordinates of the separate curves. It is highly desirable that each filter be used on a suitable color chart, and the characteristics noted in a book, before it is used.

## POLARIZING SCREENS

### 15. GLARE IN PHOTOGRAPHY

In laboratory photography the criminalistician will frequently encounter subjects which reflect an excessive amount of light in certain areas or directions, thus giving an undesirable glare. In photographing, such an area will be reproduced as a greatly overexposed part of the print, in which there is little dis-



(a)



(b)

**Fig. 120. Partial removal of glare from a fingerprint on a curved surface: (a) without polarizing screens; (b) with polarizing screens.**

cernible detail. If the area in question is of significance to the evidence, elimination of the glare becomes a problem of some importance. Curved surfaces are particularly troublesome since they will reflect a glare in certain areas regardless of the angle of illumination. Metal, glass, and similar specular surfaces will be more difficult than dull or matte surfaces.

The most common cases in which the problem of glare will arise are cases of fingerprints on the curved surfaces of a bottle (Fig. 120), can, bar, doorknob, or car door handle. In automobile accident investigation the problem will be encountered when the fender contains some mark or pattern of evidential value.

Polarizing screens are the means used to diminish undesirable reflection.



To use these screens effectively it is necessary to have an elementary knowledge of the phenomenon of polarization. This knowledge will be of some assistance also in microscopic examinations by means of polarized light, where it will be found that the polarizing properties of a substance are helpful in its identification, or in a comparison with another substance.

## 16. POLARIZED LIGHT

Light is propagated by means of transverse waves. In these waves the direction of vibration is perpendicular to the direction of propagation. The transverse vibrations ordinarily take place in all planes. It is possible, however, to limit these vibrations to only one plane. The light is then said to be *plane polarized*. The methods by which this can be done are the following:

### Crystals

The most familiar of these crystals is Iceland spar. It has the property of restricting the vibrations of light waves to one plane. The effect of one of these crystals is similar to that of a grating on a vibrating rope. The rope is constrained to vibrate in a plane parallel to the grating elements. If the rope must now pass through a second grating the full amplitude of the vibration is maintained only when the bars of the second grating are parallel to those of the first. If bars of the second are at right angles to the first, the vibration ceases completely. At intermediate positions the vibration is transmitted with an amplitude that depends on the angle through which the second grating is turned. If two Nicol prisms are placed with their principal planes parallel, the transmitted light is of maximum intensity. If the prisms are placed with principal planes at right angles, light incident on the second prism will not be transmitted and complete extinction results. Intermediate positions will transmit varying intensities of light. The first prism through which the light passes is called the *polarizer*; the second is called the *analyzer*.

### Scattering

Light scattered from small particles is plane polarized. The blue of the sky is due to the scattering of the sun's light by small particles in the atmosphere.

### Reflection

If a light is reflected from a pile of thin glass plates at an angle of slightly less than 60 degrees, the reflected light is found to be plane polarized. The transmitted beam is also polarized. Light reflected from nonmetallic surfaces such as water or glass usually is partially polarized. The angle  $i$  of the maximum polarization is given by Brewster's law:

$$\tan i = n$$

where  $n$  is the refractive index of the substance.



## 17. POLARIZING SCREENS IN PHOTOGRAPHY

Application of the properties of light just described is made to photography by the use of polarizing screens. These screens consist of sheets of a large number of slender, parallel crystals. One screen is designed to be placed over the lens. If the light is already polarized, rotation of this screen will diminish the intensity of the light on the plate. Another screen is placed in front of the light source so that only polarized light is transmitted to the subject. This second screen behaves as a polarizer; the first screen is an analyzer.

## 18. VARIOUS SURFACES

### Metallic Surfaces

On metallic surfaces there is no partial polarization because the reflection is specular, i.e., at the surface; hence the two screens must be used in subduing undesirable reflections. If the reflection is along one direction, rotation of the screen on the lens will usually give a position where the reflection is greatly diminished. If however the reflection is not along one direction, as on a curved or twisted surface, no one position of the rotating screen will subdue all the reflections.

### Nonmetallic Surfaces

One screen only need be used on surfaces such as glass, varnished or lacquered objects, liquids, linoleum, tile, grained wood, leather, fabrics, etc. The light reflected from these surfaces is polarized by reflection. Since, however, the polarization is ordinarily only partial, and no great degree of extinction should be expected, the angle at which the camera is placed is of importance (as would be expected from Brewster's law). The greatest effect is obtained when the camera is tilted at an angle of about 35 degrees to the subject. With small subjects, naturally, the subject can be tilted with respect to the camera and lights. Photographs taken under these lighting conditions are excellent for the purpose of revealing the actual texture of the surface. In certain types of document examination such photographs may be of great assistance. When it is found that the use of one screen is not effective in reducing the unwanted reflection, a photograph should also be made using the second screen, in front of the light source. The use of two screens is frequently useless when the subject is an irregular surface. Polarized light specularly reflected from polished surfaces remains polarized. If, however, the polarized light is reflected from an irregular surface such as a beady surface, it is again depolarized.

### Photographs in Daylight

In outdoor pictures the intensity of the light from a blue sky can be greatly diminished by use of a polarizing screen in front of the lens. This reduction of the luminosity of the sky is helpful where it is desired to make the foreground stand out in contrast to the sky. In photographing automobile accidents, many



undesirable reflections are encountered on the various curved surfaces of the vehicle. A polarizing screen may help in these cases to reveal detail in these surfaces which would otherwise be obscured by the reflection. The automobile should be photographed in open shade. It should be remembered that light from a blue sky is more strongly polarized in the direction at right angles to the sun's rays.

## 19. EXPOSURE

The use of polarizing screens naturally diminishes the intensity of the light incident on the photographic plate. An increase in exposure is necessary. For the Kodak Pola-Screen over lens alone the manufacturers give the following

	<i>Sunlight and Tungsten</i>
Materials	2.5
Materials	?
	?

Depending upon the material, per cent more exposure may be necessary in some cases.

When two screens are used — one on the lens and one in front of the light source — the exposure must be again increased. A factor of 4 or 8 is sometimes recommended. It will be found, however, that the exposure depends upon the angle through which the screen on the lens has been rotated. A factor of 20 may be necessary when the intensity is greatly reduced by the lens screen. No general recommendations, then, can be made. Careful notes should be made on the lighting conditions and the subject in individual cases. These notes will be found of great value in predicting the exposure in future cases of similar nature.

## EXERCISES

1. Photograph the spectrum or the colored reproduction of the spectrum as follows: first with a process film, second with orthochromatic, and finally with panchromatic. Compare the resulting prints with the original.

2. Collect six small pieces or swatches of suit material of various colors such as brown, black, gray, etc. Stain each piece with a central spot of blood about 2 cm in diameter. Arrange the pieces in a rectangular outline and photograph three times, using the three films prescribed in exercise 1 above. Examine the prints carefully from the point of view of contrast between the blood and the cloth.

3. In the photographic darkroom with a red safelight examine a number of red objects such as a tie or cigarette package. Why do they appear white?

4. Examine, under a red safelight in the darkroom, a photograph printed on buff paper and note the contrast. Now look at the same picture in white light. Account for the difference.

5. Examine the print mentioned in exercise 4 under a yellow-green filter. Account for the more natural appearance of the print.

6. If a polarizing microscope is available, focus the instrument on a hair. Rotate the analyzer at the ocular and observe the colors and the varying intensity of illumination.



7. Using the polarizing screen for the camera lens, look through the screen at the blue sky. Rotate the screen and observe the effect. Face the screen in different directions and again notice the effect.

8. Examine some surface such as linoleum or glass with the screen. Rotate the screen, observing the effect. Vary the angle of view and determine approximately which angle is best for examining the texture of the material.

9. Place a fingerprint on the side of a bottle. Photograph this print using a polarizing screen in front of the light source and a screen on the lens to reduce the reflection.

10. Repeat exercise 9 using a bright metal cylinder such as a tin can or a piece of chromium-plated material. Rotate the screen on the lens for maximum extinction. Estimate the exposure. Determine the correct exposure by means of test strips on the negative; i.e., pull out the plate holder partially at different distances for 4 sec, 16 sec, 64 sec, 4 min 16 sec, etc.

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# CHAPTER 16

## PHOTOGRAPHING FINGERPRINTS

of the crime, some wear or other  
often the most valuable piece of circum-  
stantial evidence in a case. Unfortunately, it is all too often one of the most perishable  
pieces of physical evidence. A careless sweep of the hand and it is a valueless  
smear; an unskilled stroke of a brush and its fine detail is lost; the wrong choice  
of development process and it is irretrievably destroyed. If the print is found  
on a portable object such as a knife or glass, it may be damaged in transit to the  
laboratory. The obvious precaution to take against these contingencies is that  
of photographing the print *in situ*. This should be done first, if possible, without  
developing (by powder or other means) the fingerprint; second, a photograph  
should also be made after the print is developed. Frequently, however, it will  
be found that the photography is quite difficult and that the resources of the  
studio are needed. A photograph should nevertheless be attempted on the spot.  
The object on which the print lies should then be transported to the laboratory,  
if it is at all possible, and again photographed. In fact, as a general rule it is  
well to remove all portable objects bearing prints to the laboratory so that the  
original print can be preserved in evidence.

### 2. THE CAMERA

It is not necessary to use special equipment in photographing fingerprints.  
The aim of fingerprint photography is to produce ultimately a photograph of a  
black print on a light background in the scale of one-to-one. Practically any  
camera of good quality can be used for this purpose in an emergency. There are,  
however, several cameras designed especially for fingerprint photography. One  
model is shown in Fig. 121. This is a fixed-focus type of camera which photo-  
graphs the print in one-to-one size. The camera is held flush against the print.  
Illuminating the print are four small lamps operated by batteries and contained  
within the camera. The film used is of  $2\frac{1}{4}$  by  $3\frac{1}{4}$  size. This camera is also available  
so that ordinary 110-volt. household current may be used as the energizing



source for the lamps. The latter model is more useful in the laboratory than in the field.

It is not advisable to rely only upon the fixed-focus type of camera when going to the scene of a crime for the examination of fingerprints. Very often the print is so located that it is impossible to place such a camera so that the front is in contact with the surface bearing the print. In such a situation the fixed-focus camera is useless since, when it is placed a few millimeters away from the surface, the image will be out of focus. It is also inadvisable to place complete



**Fig. 121. The fixed-focus fingerprint camera.**

reliance upon a built-in lighting unit because of the danger of run-down or defective batteries. A light meter should always be used with this camera to test the illumination and thus calculate the exposure.

When it is necessary to visit the scene of a crime for the purpose of photographing fingerprints, the police scientist should bring with him, in addition to a fingerprint camera, an all-purpose camera such as a Leica, Contax, or any other good 35-mm camera, together with filters. The Leica type can be equipped with an auxiliary apparatus which will yield a one-to-one size photograph. In addition, it is possible with such a camera to photograph prints in places inaccessible to a fingerprint camera. In these situations the scale will, of course, be no longer one-to-one; hence a ruler should be included in the picture. For this latter type photograph a 4 by 5 size camera would also serve well.



### 3. PHOTOGRAPHING BEFORE DEVELOPING THE FINGERPRINT

Every effort should be made to obtain a photograph of the fingerprint before the print is developed with powder or by other means. Significant details of the print may be obliterated in powdering if this is not carefully done. When the print consists of black lines on a white surface such as would be made by a dirty hand on white woodwork, direct lighting will produce a satisfactory photograph. When, however, the print is produced by perspiration and lies on a light surface, as in the case of a fingerprint on the blade of a breadknife, it is necessary to experiment with the illumination. Side lighting at the proper angle will usually give good results. The use of filters and polarizing screens should always be considered in more difficult cases of background or unwanted reflections.

### 4. FILTERS AND FILM

The choice of powder used in developing the fingerprint will depend upon the result desired in the photographic image. Naturally, a black print on a light background is the ultimate aim of the police scientist because the comparison prints of suspects will be black on white. If it is necessary for proper contrast to photograph the print as white on a black background, a transparency will be made later so that the final print will be black on white. The information given in Chapter 15 will be applicable here. The choice of film used can be limited to process and panchromatic film. Since process film is approximately equivalent to a panchromatic film used with a blue filter, it is possible for the photographer to work only with a panchromatic film; the great advantage in contrast, however, offered by process recommends its use wherever possible.

When a panchromatic film is used, the best film for the purpose is a process panchromatic film because of the increased contrast. We shall in our discussion refer to both process and panchromatic film. (Ortho film can be used extensively in this work, but its inclusion here would unnecessarily complicate the discussion, since panchromatic film and a filter can always be used instead.)



**Fig. 122.** Black powder on a green and white background. An orthochromatic film and a green filter were used.

If the fingerprint is found on a light-colored background, it is desirable to develop it with black powder. Where the color of the background is blue or almost white, a process film should be used. If the background is any other color (viz., yellow, green, or red), a panchromatic film should be used with a filter which will render the background as light as possible, i.e., a filter of the same color as the background. For example, a black print on a yellow background will require a yellow filter. It would be a serious error to use a process film on such a background, since process is sensitive only to blue, and would thus give a black print on a black background if the background is a true yellow.



When it is decided that the fingerprint must be developed with white powder to attain contrast or because of the adhesive quality required, the problem of the photographer lies in rendering the print white and the background black. Where the background is of some uniform color other than blue, contrast is achieved by using process film (or panchromatic with a blue filter). If the background is blue, a panchromatic film without filter will be satisfactory, although a red filter (Wratten F) will give better results. Prints on knife blades, silverware, and glass should be developed with white powder and photographed with process film.

Many simplifying assumptions have been made in the examples just discussed. The terms "uniformly colored background," "yellow," and "blue," have very little meaning unless specific wave lengths are intended. A theoretical discussion in these terms is useful only in laying down general principles of attack. In practice a series of "probably suitable" filters should always be used in place of conjecture. The print as seen through the filter is a fair approximation to the image which will be yielded by panchromatic film.

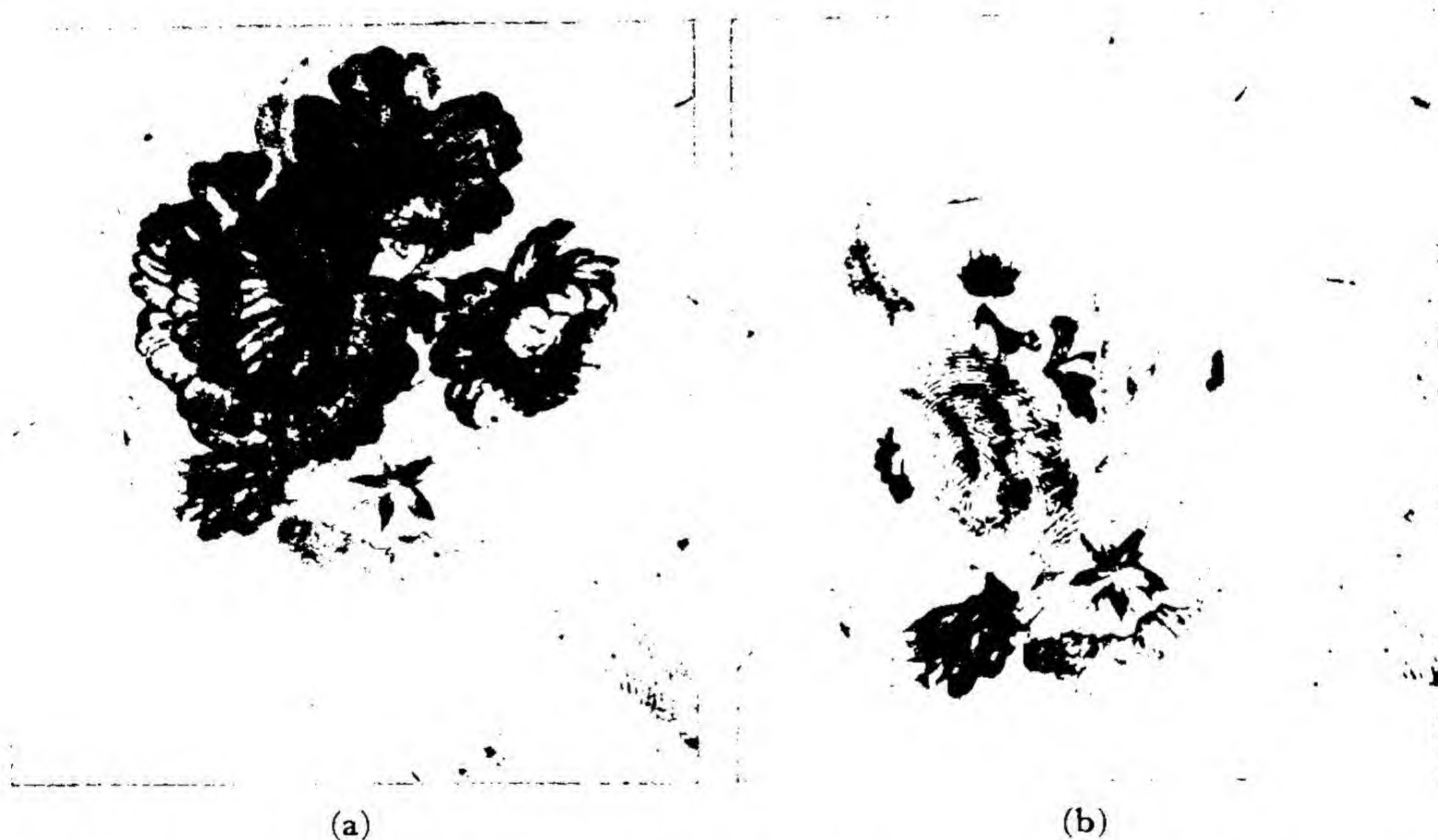


Fig. 123. A fingerprint on a blue and white dinner plate, developed with red powder and photographed (a) with a pan film; (b) with a process film.

## 5. MULTICOLOR BACKGROUNDS AND COLORED POWDERS

Frequently the fingerprint lies on a background which includes several colors. For example, the dinner plate in Fig. 123 was received in evidence in a burglary. The plate was very dark blue and white. A print lay in an area which included both colors. If black powder had been used, it would have been extremely difficult to achieve visual contrast in the blue areas; if white had been used, the same difficulty would have arisen with respect to the white areas. The use of a red powder and a process film gave a satisfactory photograph, the red



appearing black on both the white and blue. Many other simple problems of multicolored backgrounds suggest themselves; their solutions, however, follow the same lines as in the plate example.

## 6. FLUORESCENT POWDERS AND ULTRAVIOLET LIGHT

It is obvious that the use of colored powders and filters will not solve all cases of varicolored backgrounds. In difficult cases the print should be developed with



(a)



(b)

**Fig. 124. Fingerprint developed with black powder on a red and white background (a) using process film; (b) using a pan film and a red filter.**

a fluorescent powder such as anthracene, chrysene, fluoranthene, or uranyl phosphate. The print will then fluoresce under ultraviolet light and may be photographed as described in Chapter 17. The resulting print will of course be white on black. Before applying a fluorescent powder to any surface, it is advisable to expose the object to the ultraviolet. It is possible that the surface itself is fluorescent and will thus destroy the desired contrast. In the latter case a non-fluorescent powder should be used and a photograph taken under ultraviolet light.

## 7. INFRA-RED

Another method applicable in the case of difficult backgrounds is that of infra-red photography, a subject which will be treated in the next chapter. A powder such as graphite or lampblack which is opaque in the infra-red region should be used. If the background of the print is transparent in this region, an infra-red photograph will give the desired contrast. Obviously, it is necessary to first make an infra-red picture of the object to determine its characteristics under infra-red radiation, before applying the powder.

## 8. FINGERPRINTS ON GLASS AND MIRRORS

It is not uncommon to find two fingerprints in corresponding positions on opposite sides of a pane of glass. Without special precautions a photograph of one print will include the other, resulting in a confusing picture. The simplest way of resolving this difficulty is to illuminate the glass surface obliquely to exceed the critical angle, so that total reflection exists at the surface nearer the



camera. The rear surface will then be quite dark since no light is reaching it. By photographing each print in this manner, no confusion will arise.

Another method of treating this case assumes a knowledge of the existence of the prints before development. One of the prints is developed with lead carbonate; the other remains untouched. The developed print is photographed.



Fig. 125. Black powder on a red background, using an ortho film. Pan film and a red filter should be used.



Fig. 126. Black powder on yellow paper. Process pan film and a G filter were used.

A jet of hydrogen sulfide is now directed against the print; a chemical reaction takes place ( $\text{PbCO}_3 + \text{H}_2\text{S} \longrightarrow \text{PbS} \downarrow + \text{H}_2\text{O} + \text{CO}_2 \uparrow$ ) resulting in the darkening of the print. The hydrogen sulfide must be carefully directed against the print and a long interval of time permitted for the darkening to take place. A moist atmosphere helps to speed up the reaction; in the laboratory, a steam generator may be directed against the print. The other print is now developed



(a)



(b)

Fig. 127. Black powder on a blue and white background, using (a) a pan film; (b) a process.

with a white powder. A sheet of black paper is held behind the glass and a photograph made without any interference from the blackened sulfide print.

A fingerprint on the surface of a mirror offers a similar problem. The image of the print in the mirror may be confused with the print itself. Some authors



TABLE 6.

COLOR OF BACKGROUND	COLOR OF FINGERPRINT POWDER	FILM	COLOR OF FILTER	WRATTEN TYPE	RESULT	TRANS- PARENCY
Blue	1) Black	Process	None	—	Black print on white	No
Blue	2) White	Pan	Red	F No. 29	White print on black	Yes
Blue	3) White	Ortho	Green	B No. 58	White print on black	Yes
Blue-Green	1) Black	Process	None	—	Black print on white	No
Blue-Green	2) White	Pan	Red	F No. 29	White print on black	Yes
Green	1) White	Process	None	—	White print on black	Yes
Green	2) White	Pan	Red	F No. 29	White print on black	Yes
Yellow	1) White	Process	None	—	Black print on white	No
Yellow (light)	2) Black	Pan	None	—	White print on black	Yes
Yellow	3) White	Pan	Blue	C5 No. 47	White print on black	Yes
Red	1) White	Process or Ortho	None	—	White print on black	Yes
Red	2) White	Pan or Ortho	Blue	—	Black print on white	No
Red (bright)	3) Black	Pan	None	—	White print on black	Yes
Blue and Yellow	1) White or Red	Pan	Red	F No. 29	White print on black	Yes
Blue and Red	White	Ortho	Yellow	K1 No. 6	White print on black	Yes
Green and Yellow	1) White	Process	None	—	White print on black	Yes
Green and Yellow	2) White	Pan	Red	—	White print on black	Yes
Green and Red	White	Process	None	—	White print on black	Yes
Yellow and Red	White	Process	None	—	White print on black	Yes
Blue, Green, and Red	Fluorescent	Pan	Use ultraviolet light source	2A	White print on black	Yes
Black and White	1) Fluorescent 2) Black	Same as above Infra-red		No. 87	Black print on white	No

(If the multicolored backgrounds are fairly light, a black powder with a pan film will be successful. The backgrounds should first be tested for their fluorescent and infra-red characteristics before using the latter methods.)



have recommended removing the reflecting surface at the back of the mirror and then photographing the print in the usual manner. It will be found, however, that the difficulty involved is a trivial one. Oblique lighting which leaves the reflecting surface dark offers one solution. Another solution lies in focusing critically on the print and photographing with a long focal length camera at a wide opening such as  $f$  4.5. The focus then is on the print itself and not on the image, which is approximately a centimeter in back of the print. Moreover, if the camera is placed parallel to the mirror with the center of the print lying approximately on the optic axis of the camera, the image and print will be exactly superimposed and the difficulty thus resolved.

### 9. TRANSPARENCIES FOR WHITE PRINTS ON BLACK

The conventional manner of examining prints requires a black print on a white surface. A fingerprint expert examining a white print on a black surface is confronted with what appears to be a negative of a fingerprint photograph. The exigencies of photography, among other things, frequently require, however, the use of white powder. In such cases a transparency must be made from the original negative. This is done in the darkroom by placing the original negative in a frame and placing on it a sheet of medium-scale film. The frame should have spring clamps to press the films together. The films are placed notch to notch. This precaution must be taken to prevent a reversal of the relative position of the print. The frame is placed on the floor or table and exposed to the ceiling light for a second or more, as determined by experience. The photographic print is then made from this negative in the usual manner.

On page 214 a simplified table for photographing fingerprints is given as a guide to the beginner. Several precautions must be observed in using it. First, recommendations of film and filter are all made on the assumption that the color of the background is "pure"; i.e., the wave lengths reflected by it are grouped in a narrow spectral region about the dominant wave length. That such colors are rarely found in nature was pointed out in Chapter 15. Second, the same assumption is made concerning the transmission of filters; in practice it will be found that a filter transmits also in regions neighboring the dominant color. Third, the color sense of the individual is assumed to be normal.

In summary, it should be stated that the results in the photography of colored backgrounds are not accurately predictable. The fingerprint photographer must have a good knowledge of the characteristics of film materials and filters and he should make a visual inspection of the print with the filter; finally, he should be prepared to experiment in the event of initial failure.

### EXERCISES

1. If a fingerprint camera is available, measure the illumination by means of a light meter. The  $f$  number will be found on the lens mount or in a catalogue. What is the bellows extension of the camera, knowing that the plate image is of the same size as the object? From this information give the approximate value of the exposure time.



2. Place fingerprints on a pane of glass, on a dark metallic surface, and on a knife. Photograph before developing and after developing.

3. Place a fingerprint on a yellow, a blue, and a red background. Develop and photograph. In each case photograph using the proper filter and film.

4. Select a multicolor background such as blue and white. Place and develop a fingerprint on the surface and photograph using the proper filter and film.

5. Using the same surface as in exercise 4, develop with a fluorescent powder and photograph in ultraviolet light.

6. Selecting a surface which is known to radiate in the infra-red region, develop a fingerprint with graphite. Photograph with infra-red film using a filter such as Wratten 87.

7. Place two fingerprints in corresponding positions on opposite sides of a thick pane of glass such as an automobile window. Photograph without developing, using oblique lighting. Develop and photograph using the hydrogen sulfide method.

8. Select a negative of a white fingerprint on black and make three transparencies of widely different densities. Print the transparencies noting the details of the fingerprints. Use paper of different contrast values. Make two more transparencies using a process and a high-speed film. Does the high-speed film, because of its longer scale, retain more detail?

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# CHAPTER 17

## ULTRAVIOLET AND INFRA-RED PHOTOGRAPHY

### PHOTOGRAPHY IN ULTRAVIOLET RADIATION

In Chapter 21 the various applications of ultraviolet radiation to the field of criminalistics are described. When positive results are achieved by means of such an examination, it is desirable to record this evidence photographically. Such a photographic record provides an excellent court exhibit, and in certain cases, lends a degree of objectivity to the testimony. There are two general kinds of photograph made in an ultraviolet examination: first, photographs of fluorescent substances by the visible rays which they emit; second, photographs recording the reflected and unaltered ultraviolet radiation itself.

#### 1. FLUORESCENCE

When the desired effect of the ultraviolet examination is visible to the eye, it can be photographed in the usual manner. Photography of fluorescent substances is similar to ordinary photography except for the long exposures involved. The room must be dark except for the ultraviolet light source. Since substances may fluoresce in all regions of the visible spectrum, a panchromatic film is used. Focusing is done with a bright light on the subject because the illumination from the fluorescence is usually too faint for accurate focusing. The exposure must usually be determined by experience; it will vary with the kind of lamp used and the intensity of fluorescence, in addition to the usual variations of film speed. Under a Cooper Hewitt lamp, at  $f/4.5$  with a medium-speed panchromatic film, the exposure is usually between one and ten minutes. Of course, brilliantly fluorescing substances, such as teeth, require only a fraction of this time. Where the fluorescence is very weak, several hours may be necessary to properly expose the film. Under ordinary conditions of fluorescence the following data are applicable: with two No. 1 photoflood lamps at 45 degrees, 4 feet from the object, a Corning No. 5860 filter on each lamp, a Wratten 2A filter on the lens, and a Superpan Press, Arrow Pan Press, or Super Panchro Press film, an exposure of 2 minutes at  $f/11$ .



It is possible to photograph fluorescent objects without using any filter over the lens. Sometimes, however, this procedure does not yield satisfactory contrast because of the distinct visibility of the background. It should be remembered that films are quite sensitive in the blue and ultraviolet region; hence the relatively faint image of the background seen under the ultraviolet is recorded by the film much more intensely and may interfere with the true fluorescent image. It is desirable, then, to use a filter such as Wratten No. 2A, Ilford Q (No. 805), or Aviol No. 102 to cut out the light in the ultraviolet region (Fig. 128). A Wratten K2 filter may also be used. The K2 is a light yellow filter

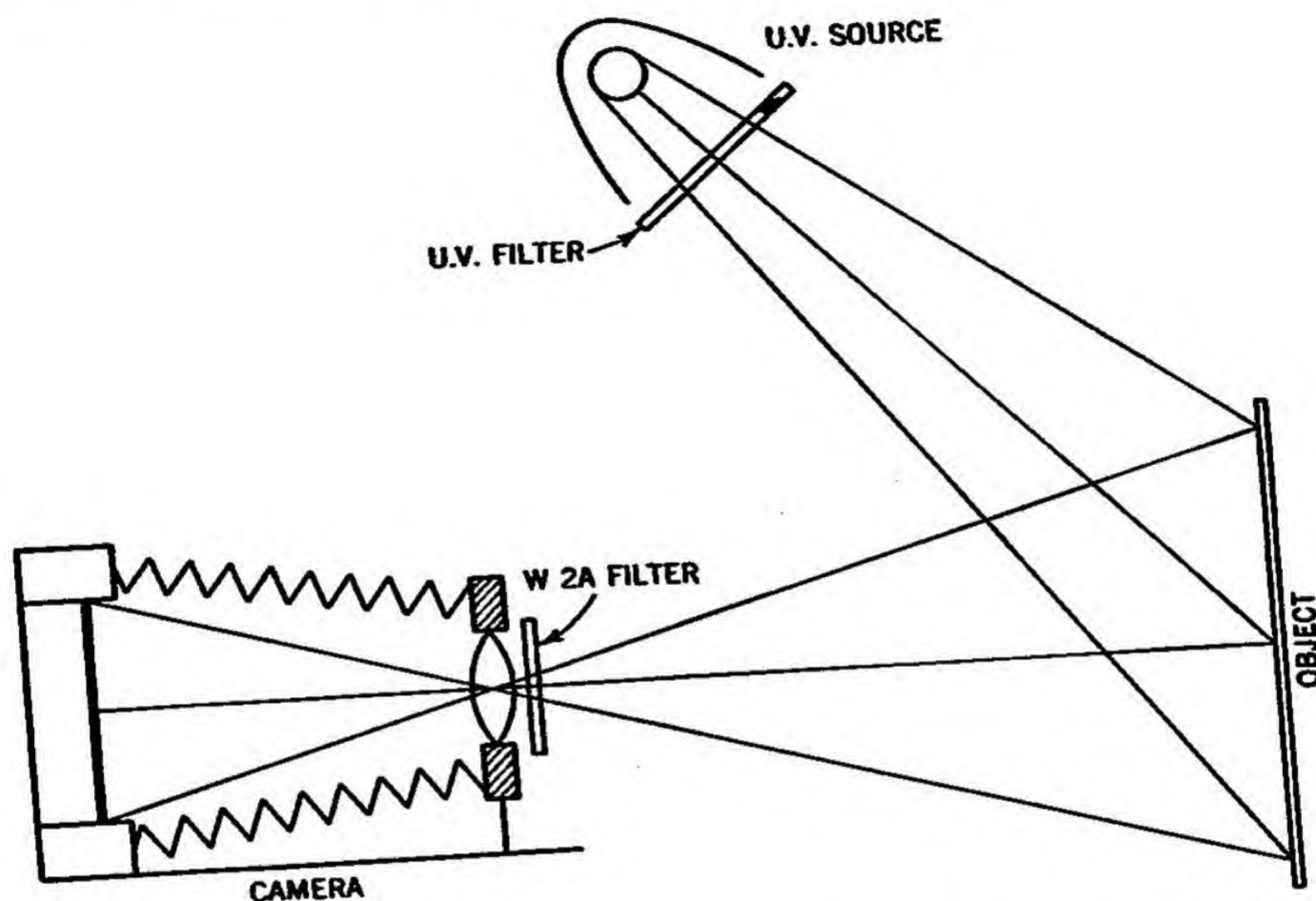


Fig. 128. Photographing fluorescent effects. A U.V. filter is placed over the light source. A yellow or green filter is placed over the lens to exclude an excess of blue light.

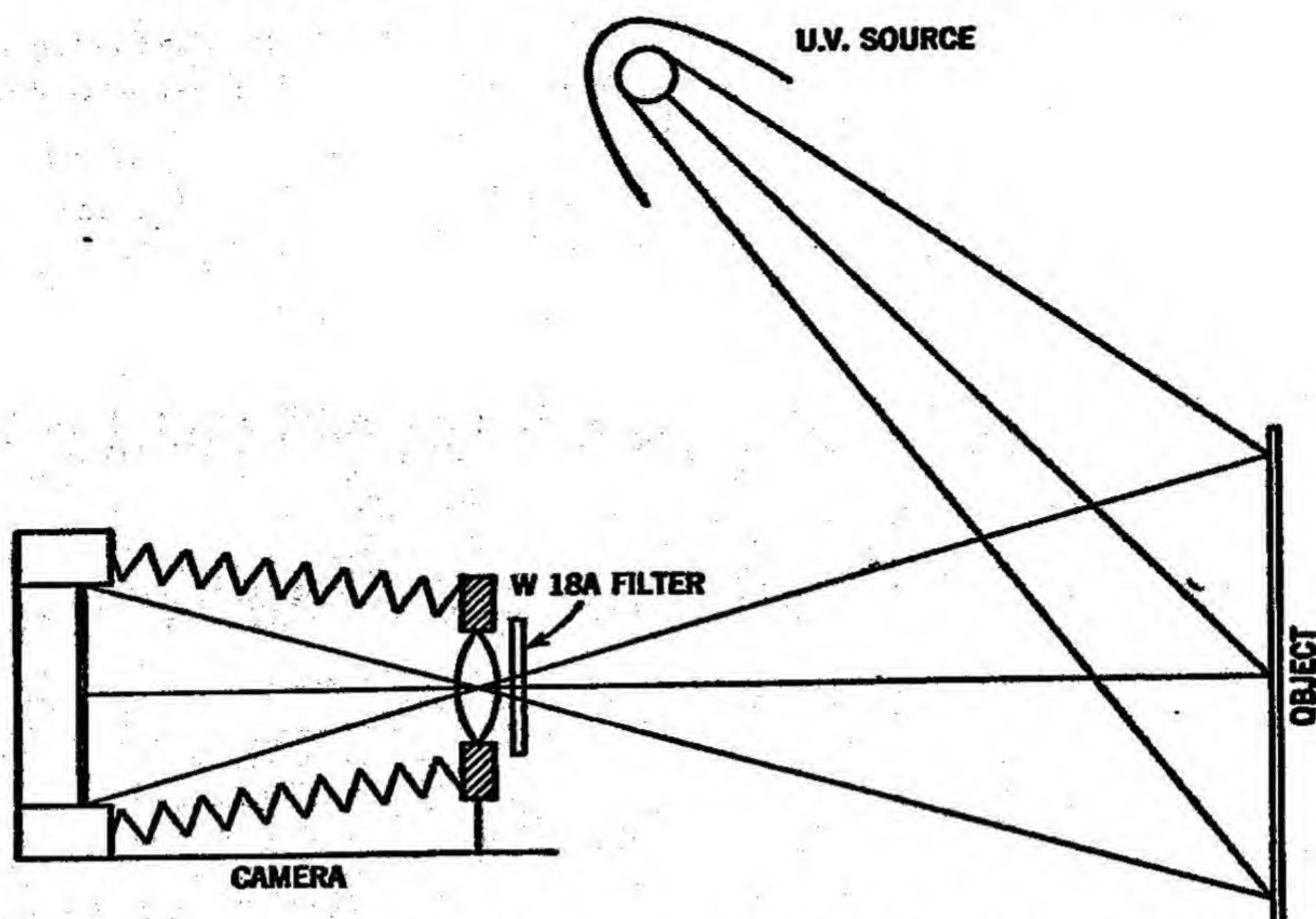
which is commonly used for outdoor snapshots because of the excessive sensitivity of film to the blue region. The authors have found a Wratten P60 filter helpful in many cases.

A good practice in ultraviolet photography of fluorescent objects is to make two photographs — one with the filter and one without. The latter photograph is made because of the possibility of losing certain fluorescent effects because of elimination by the filter of certain wave length regions which contribute to the complete picture.

## 2. PHOTOGRAPHS BY REFLECTED ULTRAVIOLET LIGHT

The visible phenomena under ultraviolet examination may often be valueless. The investigator should then have recourse to a photograph made by means of the ultraviolet wave lengths only. The results are usually unpredictable, but the trial should be made, if the equipment is available. It will be found that the

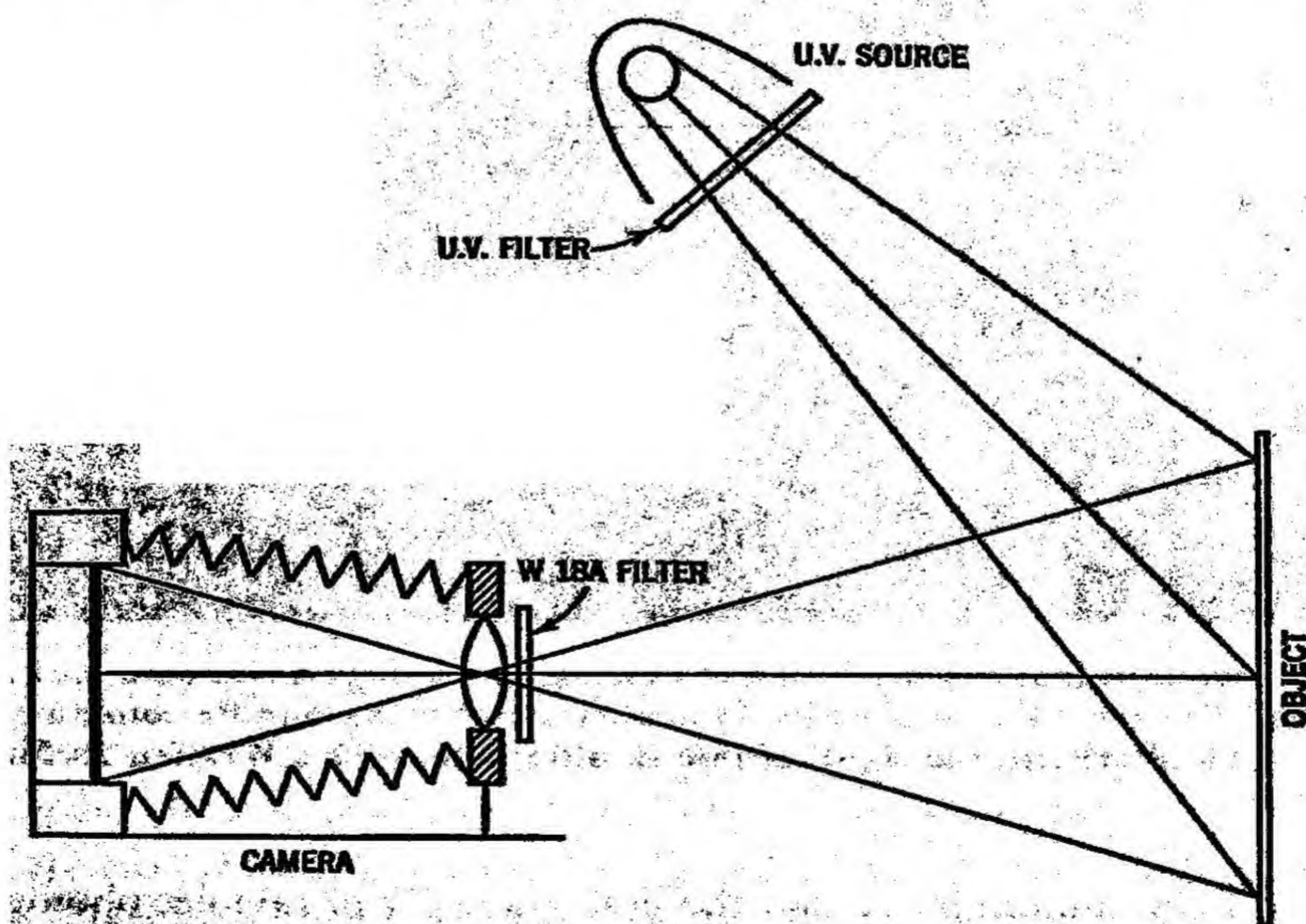




**Fig. 129. Photographing in the pure ultraviolet. The arrangement is the same as that of Fig. 128 with the exception that an 18A filter is used over the lens to exclude visible light and transmit only the ultraviolet.**

technique is especially useful in detecting differences in the absorption by ink and other coloring materials.

A filter (such as Corning Violet Ultra No. 5860) must be used in photography by pure ultraviolet light. This filter may be placed over the lens (Fig. 129)



**Fig. 130. Photographing in the pure ultraviolet. An alternative arrangement to that of Fig. 129.**



or may be fixed on the lamp (Fig. 130). When the filter is used over the lens the photograph may be made without darkening the room. With the filter over the lamp the room must be darkened. With the Hanovia lamp a series of filters is provided, each covering a different region of the ultraviolet spectrum. A Wratten No. 18A filter is suitable for placing over the camera lens to absorb the visible wave lengths when a filter is used over the lamp.

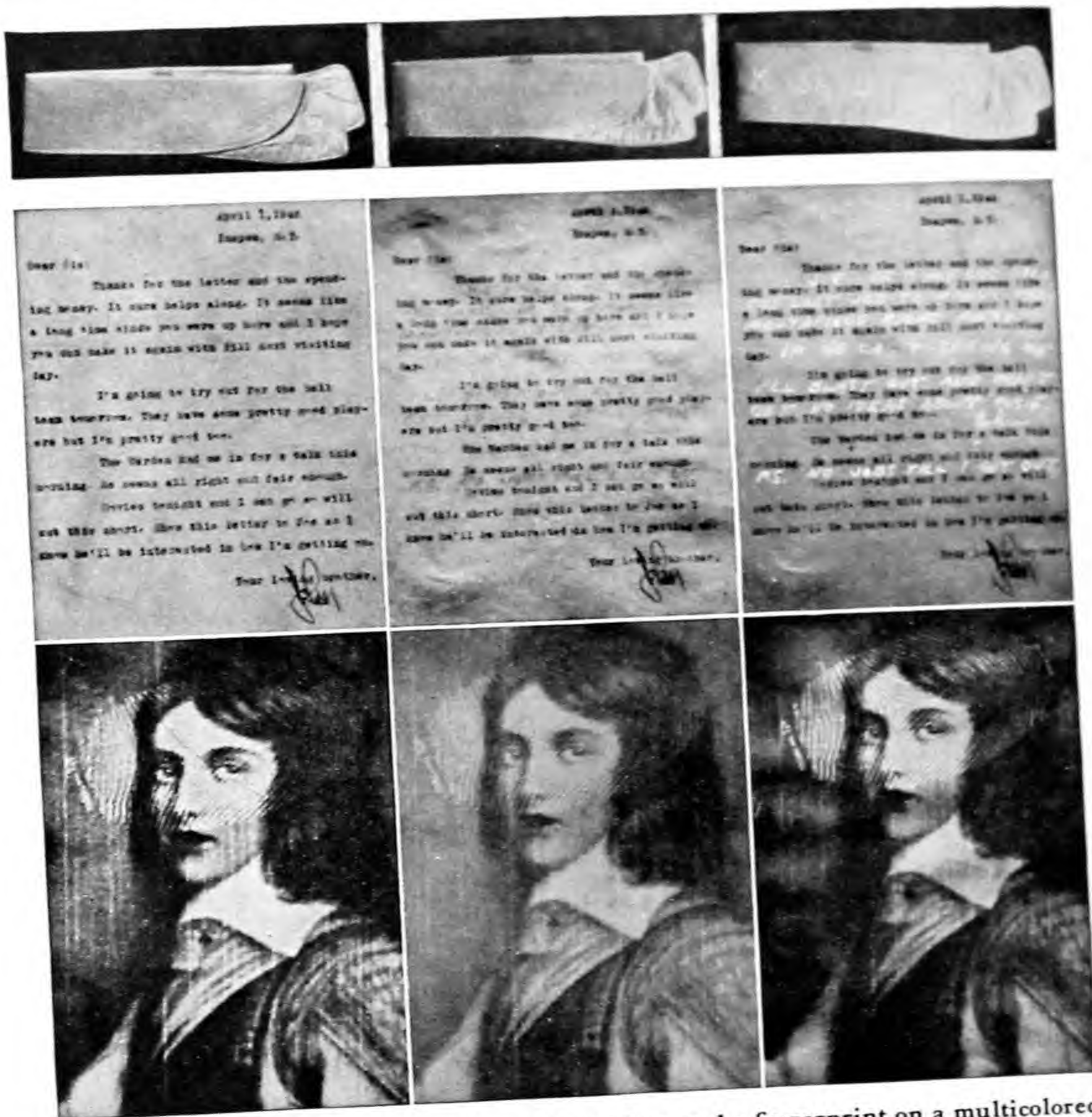


Fig. 131. Fluorescent laundry mark, secret writing, and a fingerprint on a multicolored background. The left column is taken in ordinary light; the middle column in ultraviolet without a filter; and the right column in ultraviolet with a Wratten 2A filter over the camera lens.

The ordinary camera lens is not the best suited for ultraviolet photography, since it interferes with the transmission of light in this region. A quartz lens should be used if available. The ordinary glass lens cuts off a considerable region



of the ultraviolet. Similarly, in photomicrography under ultraviolet light, it is preferable that the microscope be equipped with quartz lenses.

Since the wave lengths in the ultraviolet region are shorter than those of ordinary light waves they will come to focus at some point in front of the plane of exact focus for visible rays. Focusing of the object should first be done in the visible light. The back of the camera should then be racked in a distance of about  $\frac{1}{200}$  of the focal length of the lens. This distance is quite small — about  $\frac{1}{20}$  inch with a 10-inch lens; hence it is usually possible to solve the focusing problem by focusing in visible light and then stopping down to  $f/16$  or  $f/22$ .

Pan, ortho, or process film may be used for ultraviolet photographs since they are all sensitive in the blue-ultraviolet region. For true ultraviolet photography special emulsions sensitized for different regions of the ultraviolet should be used. Eastman Kodak Co., for example, provides a spectroscopic plate which is sensitive only to wave lengths below 5000 Å.

The following exposure data will be found useful. With two No. 1 photoflood lamps at 45 degrees, 4 feet from the object, using Superpan Press, Arrow Pan Press, or Super Panchro Press film, an exposure of 4 minutes at  $f/11$  is satisfactory with a Corning No. 5860 filter.

### 3. SOURCES OF ILLUMINATION

There are many sources of ultraviolet radiation available for police laboratories, ranging in expense from ordinary sunlight to a specially designed lamp. The choice of lamp will, of course, be made in accordance with the laboratory's budget. The following list of sources includes several of the less expensive kind:

#### Photoflood Lamps

The ordinary Photoflood lamp can be enclosed in a lightproof housing permitting the light to pass through a filter such as the Corning Violet Ultra No. 5860 or Heat Resisting Red-Purple Ultra No. 5874.

#### Carbon Arc

The type used for photomicrography is suitable. A Heat Resisting Red-Purple Ultra No. 5874 filter or Red-Purple Ultra No. 5870 filter is used.

#### Argon Lamp

The ordinary argon lamps can be used with a No. 5874 or No. 5970 filter.

#### Mercury-Vapor Lamps

These lamps are best suited for ultraviolet work. If they possess quartz tubes instead of glass, they will permit the passage of the radiation of shorter wave length. The following are common types of this lamp:

Cooper Hewitt lamp with Nico tube. The glass of the Nico tube is equivalent to an ultraviolet filter of the Corning No. 5860 type.

General Electric Uviarc burner.



Hanovia quartz lamp (Fig. 155). This lamp is enclosed in a housing which permits insertion of various filters.

If it is desired to observe fluorescent effects, any of these lamps must be enclosed in a housing and covered with a filter (where the lamp glass itself is not a filter). The examination must take place in a darkroom. When a photograph in reflected ultraviolet light is desired, the lamp need not be covered or the room darkened. The filter in this case may be placed over the camera lens. This filter will restrict the light entering the lens to the ultraviolet region. Of course, photography by reflected ultraviolet can also be done with the filter over the lamp in a darkened room. For this procedure an 18A filter is used over the lens to exclude visible radiation resulting from fluorescence.

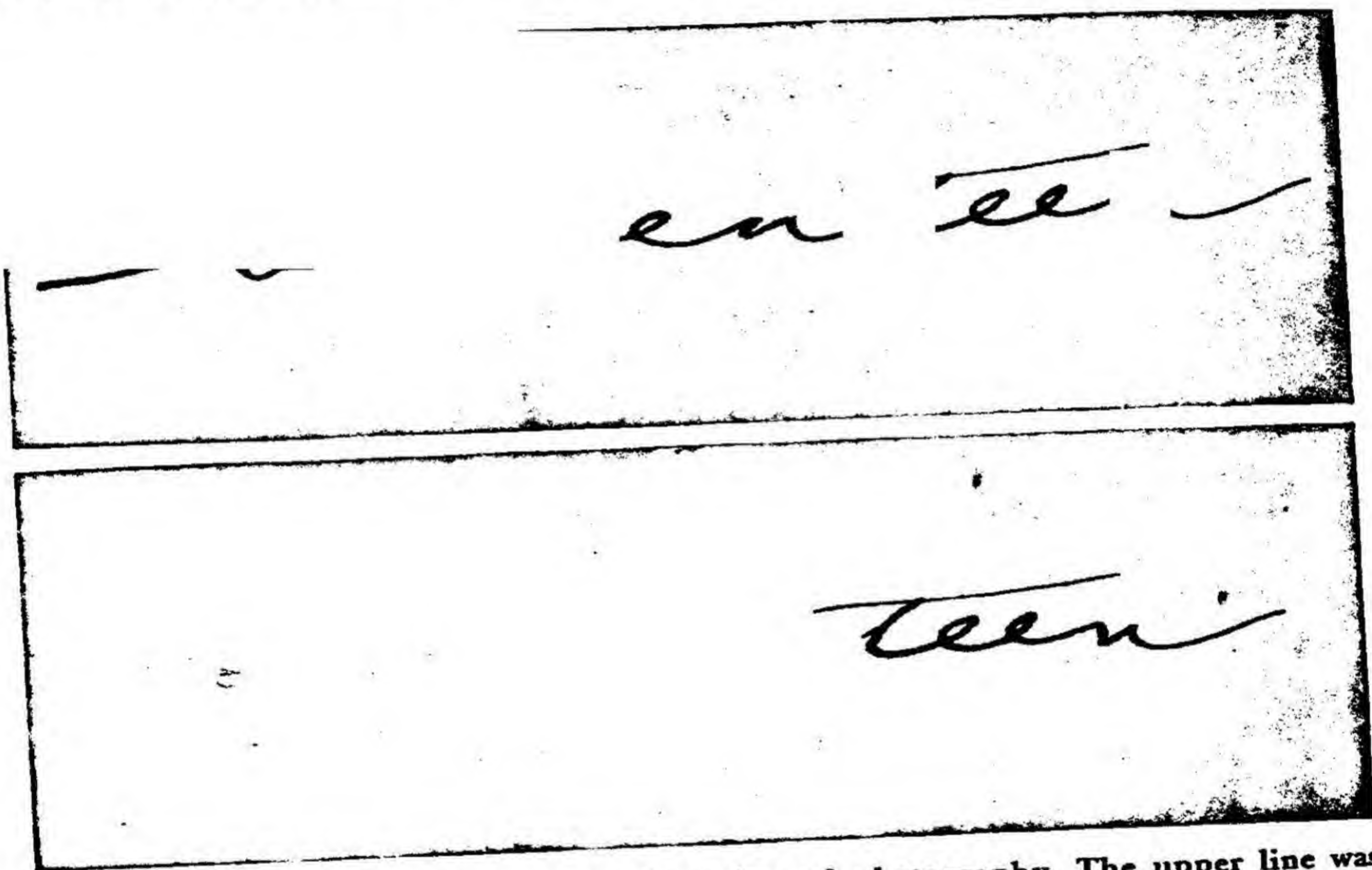


Fig. 132. The differentiation of inks by infra-red photography. The upper line was photographed without a filter; the lower line was taken with an infra-red filter.

### INFRA-RED PHOTOGRAPHY

Infra-red photographs are used in scientific criminology to reveal details which are important in evidence but which are invisible to the eye. Stains, charred documents, fraudulent paintings, altered writing, and many other subjects provide a profitable use of infra-red radiation. The applications are discussed in detail in Chapter 21.

#### 4. FILTERS

Infra-red photographs in visible light require the use of a filter. All the well-known manufacturers of photographic materials offer a series of infra-red filters



The choice of filter is dependent upon the spectral region within which the operator wishes to work. Infra-red filters can be obtained for wave lengths from 5600 A to 9300 A. Usually the filter must be selected by experiment in criminalistic work, since the results are unpredictable. The filter is, of course, of a deep red color which will absorb the shorter wave lengths. The Wratten 70 and 87 filters are sound choices for preliminary trials. Either of the following sets of filters will be found adequate for laboratory work.

TABLE 7. Infra-red Filters

EASTMAN KODAK	
Wratten Number	Lower Limit of Transmission
25	6000 A
70	6700 A
89 A	7000 A
88 A	7400 A
87	7700 A
Special, Batch 5233	9200 A
ANSCO	
Ansco Number	Lower Limit of Transmission
42	6000 A
83	7250 A
84	7500 A
85	8300 A
87	8400 A
89	9300 A

Filters below the Wratten 87 and the Ansco 84 transmit visible light as well as infra-red.

## 5. FILM AND DEVELOPMENT

Films as well as filters must be selected with regard to the desired spectral region. A film such as Eastman or Ansco infra-red film will be found satisfactory for the general work. The film is stored in a refrigerator to prevent fogging through heat. Precautions must be observed in regard to film holders. These should be opaque to heat rays, particularly if the holder is to remain loaded over a long period of time. The usual developers and developing techniques are used in processing these films with emphasis being placed on increasing contrast.

The ordinary type of infra-red film is sensitive also to the blue region of the spectrum but not to the green. It is sensitive, too, in the visible region bordering the infra-red. Since difficult infra-red problems are common in the laboratory, it is well to have at hand some of the other types of infra-red emulsions which are sensitive to different regions of the infra-red. Infra-red process plates may



be used for increased contrast such as that required in document photography. Eastman Kodak supplies emulsions for spectroscopic plates which are sensitive from 7000 Å to 12,000 Å.

## 6. LIGHT AND EXPOSURE

The two common sources of infra-red radiation are the sun and the incandescent tungsten filament lamp. The quantity of infra-red radiation in sunlight is not readily determined. There is no simple relation between visual radiation and infra-red radiation; hence an ordinary light meter cannot be used to determine the exposure of an infra-red plate in sunlight.

This, however, is not a serious difficulty for the police scientist because his work is almost invariably confined to the laboratory. Here a tungsten filament lamp gives a definite amount of infra-red radiation from this source. The reading of a visual meter can be interpreted to give the exposure of an infra-red plate. The emulsion speed of infra-red plates is usually about 1/10 that of process plates. Exact comparison should be made with two No. 1000 floodlights at a distance of 4 feet, a Weston light meter reading of 1.5 will yield a satisfactory exposure with a Wratten 87 filter.

## 7. FOCUSING

Since infra-red rays are longer than visible rays they are less refrangible and consequently come to a focus behind the visual rays (Fig. 275). Ordinary achromatic and apochromatic lenses are not corrected for infra-red. Because of this fact, the invisible infra-red image on the groundglass is located nearer to the observer than the visual image; hence the camera must be racked out a small fraction of an inch. Various recommendations for the extent of this racking out are given, but no general statement will be obtained because the degree of refraction of the infra-red rays is a function of the type of lens used. One rule given is to increase the bellows extension of the camera 0.3 to 0.4 per cent of its value after visual focusing. Since the Tessar-type lens is quite commonly used in laboratory work, the following recommendation of Zeiss is given: the increase in bellows extension should be 3 per cent of the focal length for Tessar lenses of  $f/4.5$  or  $f/3.5$  and of ordinary focal length. The best rule, however, is to determine the correction by experiment and then record the data. The difficulty can be entirely avoided by focusing on the visual image and then stopping down to a large  $f$ /number. The resulting depth of field will obviate the focusing problem.

## EXERCISES

1. Develop a fingerprint using a fluorescent powder such as anthracene, uranyl phosphate, or chrysene. Photograph the fingerprint employing an arrangement similar to that illustrated by Fig. 128.
2. Prepare a message in secret writing using lemon juice or milk as the ink. Photograph as in exercise 1. Note the difference in exposure.



3. Delete a line of ink writing from a check by means of an ink eradicator. Photograph as in exercise 1.

4. Repeat exercise 3 with the arrangement of Fig. 129.

5. Using sunlight or a white-hot incandescent carbon rod, project the spectrum on a screen by means of a prism. The spectrum will be continuous from violet to red. Blacken the bulb of a sensitive thermometer and place it in the region beyond the red end of the visible spectrum. Note the rise in temperature. What conclusion is to be drawn from this temperature rise?

6. Inscribe a name on a card using an iron tannate or gallate ink. Place a drop of blood over the writing so as to render part of the name invisible. Place the card upright in position for a photograph. At each side of the card place a hot plate or flat iron of at least 600 watts. Focus a camera for an infra-red photograph. In complete darkness expose an infra-red film for at least an hour. Develop and print as usual. No filter is needed for this experiment since no visible light is present. An opening of  $f/4.5$  may be used.

7. Select ten widely varying inks (i.e., green, red, India inks, etc.). Write the names of each ink on a sheet of paper using the corresponding ink and a clean nib for each name. Photograph in the infra-red using the Wratten 70 and 87 filters.

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# CHAPTER 18

## STEREOSCOPIC PHOTOGRAPHY

### 1. APPLICATIONS

Throughout our study of photography as a tool of the crime laboratory we have been concerned mainly with two aims: a faithful reproduction and/or a photograph to emphasize or clarify certain details.

Many opportunities will occur in scientific crime detection where employment of the stereoscopic camera will illuminate a difficult point of physical evidence. The most obvious use of this camera is that of photographing the scene of a crime such as a homicide. Here the spatial relations of the body with respect to the walls, furniture, and other objects may be of extreme importance.

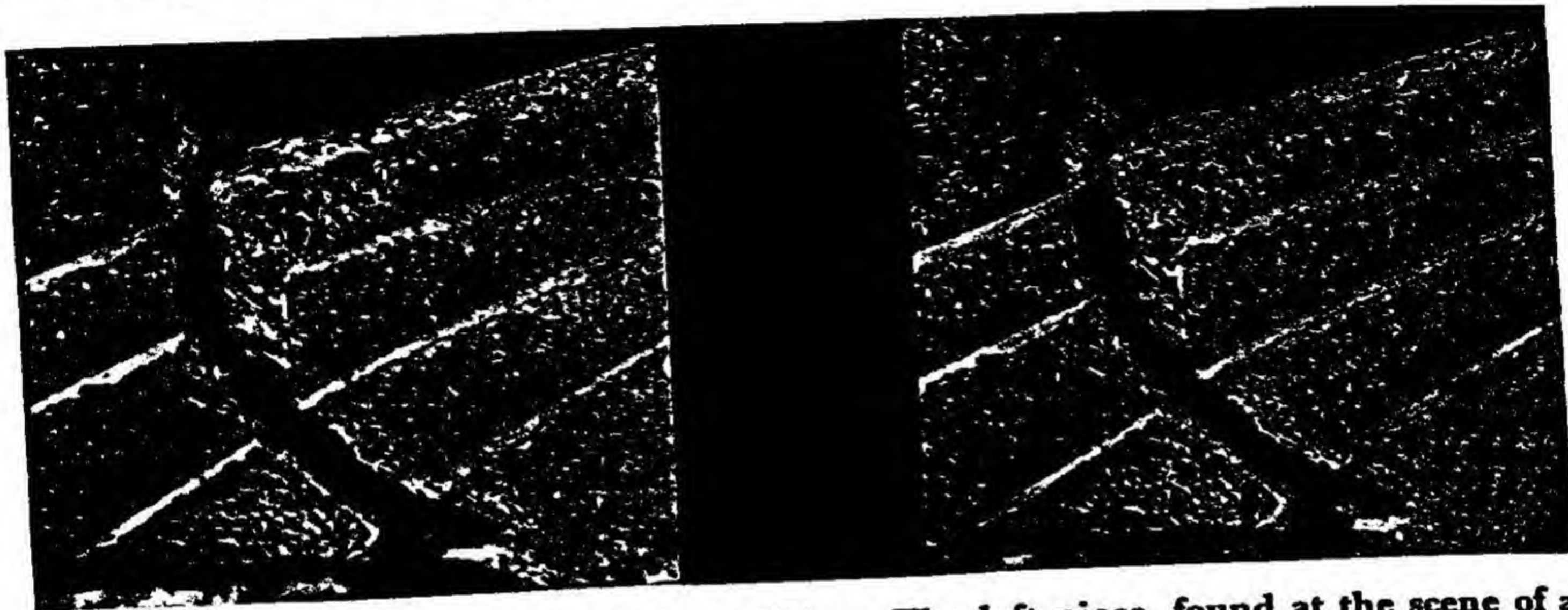


Fig. 133. A torn match found at the scene of a crime is fitted to a match book discovered on the person of a suspect.

The court usually wishes to see a photograph which is undistorted in regard to perspective and other matters. Many objections to photographs are made because of the many ways in which misrepresentation can be introduced. We have dealt with these objections by demonstrating how they can be avoided in a photograph based on scientific principles. The final argument against the photograph — that it is only a two-dimensional representation — is met in part by the stereoscopic camera.



An excellent use of stereoscopy is suggested by cases which involve the matching of parts. The following examples are illustrative of this use: (1) A match is found at the scene; a book of matches is found on a suspect. On examination it is seen that the match was torn from the suspect's match book. A stereoscopic photograph is made to show the fit (Fig. 133). (2) Glass picked up at the scene of a motor vehicle homicide is found to fit a part of the defendant's broken head lamp. The two fitted parts show a cleavage along a smooth curve of small



**Fig. 134.** Broken pieces of a radiator emblem. The left piece, found at the scene of a hit-and-run accident matches the right piece, which remained on the auto.

curvature. The convincing part of the fit is in the interior or cross-sectional areas. A simple photograph of the two pieces fitted together will fail to show the matching convincingly. A stereoscopic photograph is made first with the parts fitted together and then with the parts slightly separated. (3) Broken instruments and wires in cases of sabotage. (4) Broken parts of automobile equipment such as radiator ornaments, side mirrors, etc. in connection with motor vehicle cases (Fig. 134).

## 2. BINOCULAR VISION

In order to achieve a three-dimensional representation we must produce the photographic equivalent of binocular vision. The human eyes perceive depth mainly because the two retinal images are received from slightly different points of view — one eye is always looking behind part of the object viewed by the other eye. A popular demonstration of the necessity of binocular vision for depth perception is that of closing one eye and placing a pencil between the other eye and the wall at a distance of about two feet from the eye. Theoretically the pencil will appear to be in contact with the wall.

It is not true, however, to say that perception of depth is impossible with monocular vision. Memory and experience will assist the eye in determining the relative position of objects in space. The degree of accommodation required to bring relatively near objects into focus will help us to estimate distance. The angle subtended by the object at the eye is helpful if we know the size of the object. Difference in relative velocities to a person in motion is useful in



estimating distance. Merely changing the point of view is helpful. Side illumination also gives an impression of depth.

In the laboratory the stereoscopic camera and microscope are the instruments which are designed for three-dimensional representation. We shall treat here the principles which determine the construction and guide the use of the stereoscopic camera.

### 3. PERCEPTION OF DEPTH IN PHOTOGRAPHY

It is possible to create the sensation of relief in photography by viewing two photographs which are designed to give each eye the view which it would have

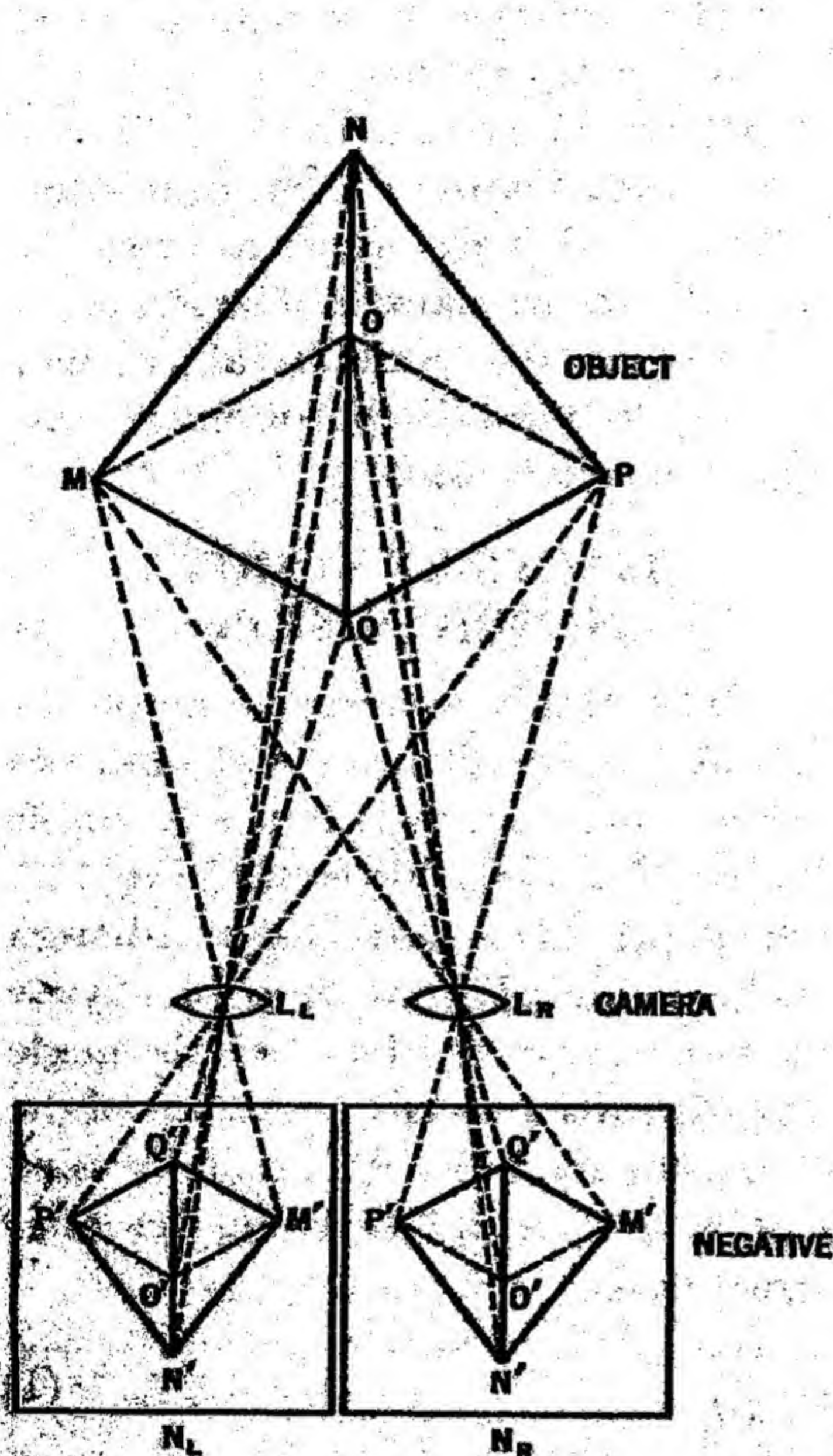


Fig. 135. Image formation in stereoscopic negatives.

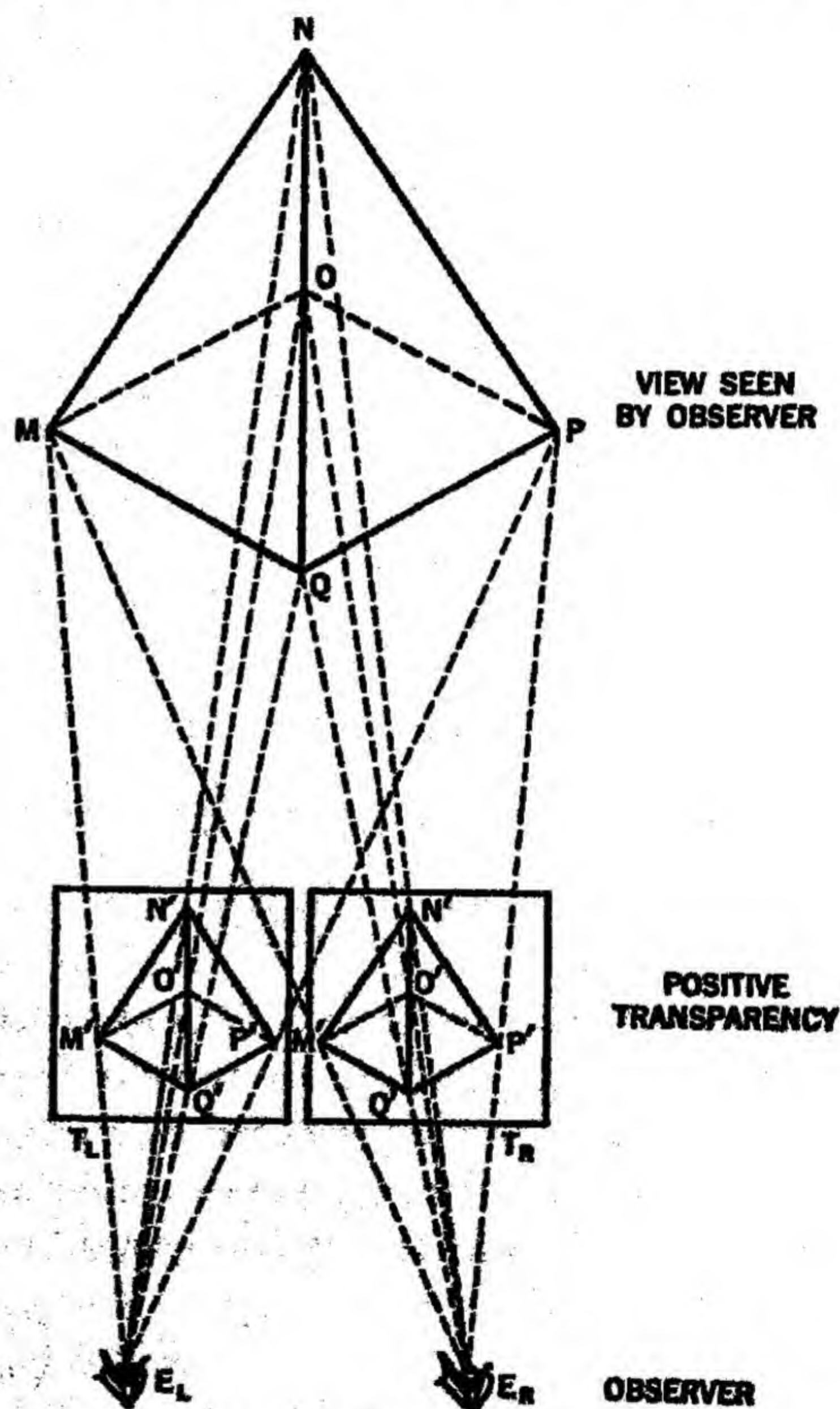


Fig. 136. Viewing the positives.

in viewing the subject itself. In making the photographs the different points of view must be separated by a distance equal to the interocular or interpupillary distance of the eyes, i.e., 62 mm or 2.5 inches (variations from this rule are employed for special effects). The photographs can be made in either of two ways: (a) A still-life subject can be photographed by making two exposures with an ordinary camera and shifting the camera parallel to the plane of the plate a distance of 2.5 inches for the second exposure; (b) a special camera



consisting of two lenses or one lens and a prism device can be used, only one exposure being necessary.

The effect of viewing the positives can be understood by examining Fig. 135. Here,  $L_L$  and  $L_R$  are the positions of the two lenses (or the single lens which is shifted between exposures). The object  $MNPQ$  is photographed on two nega-

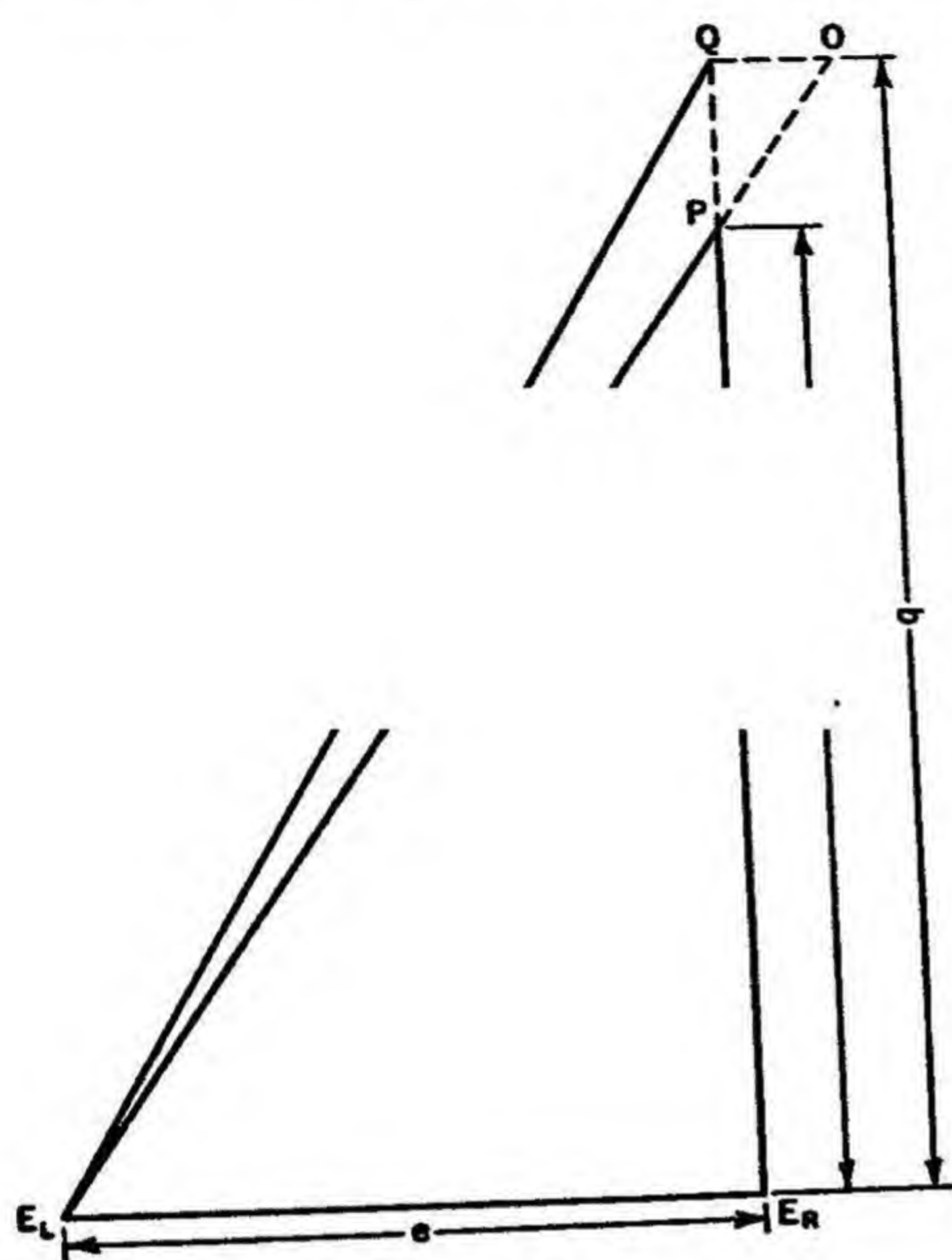


Fig. 137.

tives  $N_L$  and  $N_R$  (the left and right negatives). If now transparencies are made from these negatives and viewed from the correct viewpoints  $E_L$  and  $E_R$  (Fig. 136), i.e., from a position of the eyes corresponding to the position of the lenses with respect to the negatives, the effect of relief will be experienced. Figure 136 illustrates the effect of viewing transparencies  $T_L$  and  $T_R$  in this manner. The sensation of viewing the original subject will be experienced if the observer possesses normal vision.

#### 4. LIMITS OF STEREO-SCOPIC VISION

The ability to perceive depth diminishes with distance. The limit beyond which depth is not perceptible is approximately 700 feet. In Fig. 137, the depth  $PQ$  is perceptible although  $Q$  lies behind  $P$  from the point of view

$$\theta = e \left( \frac{1}{p} - \frac{1}{q} \right). \quad (1)$$

From this it follows that

$$PQ = q - p = \frac{pq\theta}{e}. \quad (2)$$

The minimum value of  $\theta$  for which point  $Q$  is distinguishable from point  $P$  is approximately 0.0003 radian. To determine the limit of depth perception we assume that point  $Q$  is at infinity.

Rearranging equation (2) we have

$$1 - \frac{p}{q} = \frac{p\theta}{e}. \quad (3)$$



$$\text{If } q = \infty, \quad p = \frac{e}{\theta}. \quad (4)$$

Since  $\theta = 0.0003$  radian and  $e = 2.5$  inches,  $p$  has an approximate value of 700 feet. Beyond this distance there is no direct perception of depth.

The ability to perceive depth can be enhanced with the aid of an optical instrument such as a binocular. If  $M$  is the magnifying power of the instrument and  $e'$  is its interocular distance, it can be shown that equation (2) becomes

$$q - p = \frac{pq\theta}{Me'}$$

and equation (4) becomes

$$p = \frac{e'M}{\theta}. \quad (5)$$

From this latter equation we can see that by increasing the interocular distance or by observing an enlarged image through the use of an optical instrument, it is possible to increase  $p$ ; i.e., depth can be perceived at a distance greater than 700 feet. By using five-power prism binoculars with an interocular separation of 5 inches, relief can be perceived as far as 7000 feet, according to equation (5).

For the ordinary stereoscopic camera, however, the radius of stereoscopic vision is less than that of the eyes because of the limitations imposed by the reduction in size and the graininess of the film. For a long focal length lens the limit is approximately 200 feet; with a lens of short focal length, the limit is approximately 50 feet. These limits are, of course, affected by the separation of the lenses.

## 5. STEREOSCOPIC CAMERAS

It has been pointed out that the essential element of a stereoscopic photograph is the production of two negatives from two different points of view. This may be done by moving the camera or by using a specially designed camera. The special camera can be constructed with two identical lenses or with one lens, the light beam being divided so that the light entering each half of the objective is transmitted to the corresponding negative.

Another type of stereoscopic camera is one in which the plate and the lens are permitted to slide into different positions. Figure 138 shows a camera of this type which is excellently adapted for the work of the laboratory. This camera has a fixed bellows extension so that focusing is done by sliding the whole camera on the upright bar. Two exposures are made: the plateholder and lens are first placed at one side and an exposure is then made; this procedure is repeated with the plateholder and lens moved to the other side. The camera is equipped with a set of six lenses so that magnifications from 1X to 24X can be obtained. The focal lengths range from 48 mm to 5½ inches. With these lenses the camera is equipped also for ordinary low-power photomicrography.

An excellent means of recording photographically the various aspects of the scene of a crime is that of a stereoscopic camera of the 35 mm type. The ordinary 35 mm camera can be adapted for this work by means of a stereoscopic attach-



lens which divides the beam of light as described above. A transparency is made from the negative and viewed through a special viewing device. With this transparent an inexpensive record of the details of a crime can be made in a short time. It is recommended that, as a matter of routine, such a record should be made at the scene of the crime. Since the defendant's trial usually takes place some months after the crime, many of the details of the physical surroundings of the crime will escape the memory of the expert witness on the stand. Although these details may be unimportant, the interrogating counsel will place great value on them as an indication of the reliability of the witness' testimony. It is well then, for the expert witness to refresh his memory by means of a photographic record of the scene of the crime. A strip of twenty frames will usually

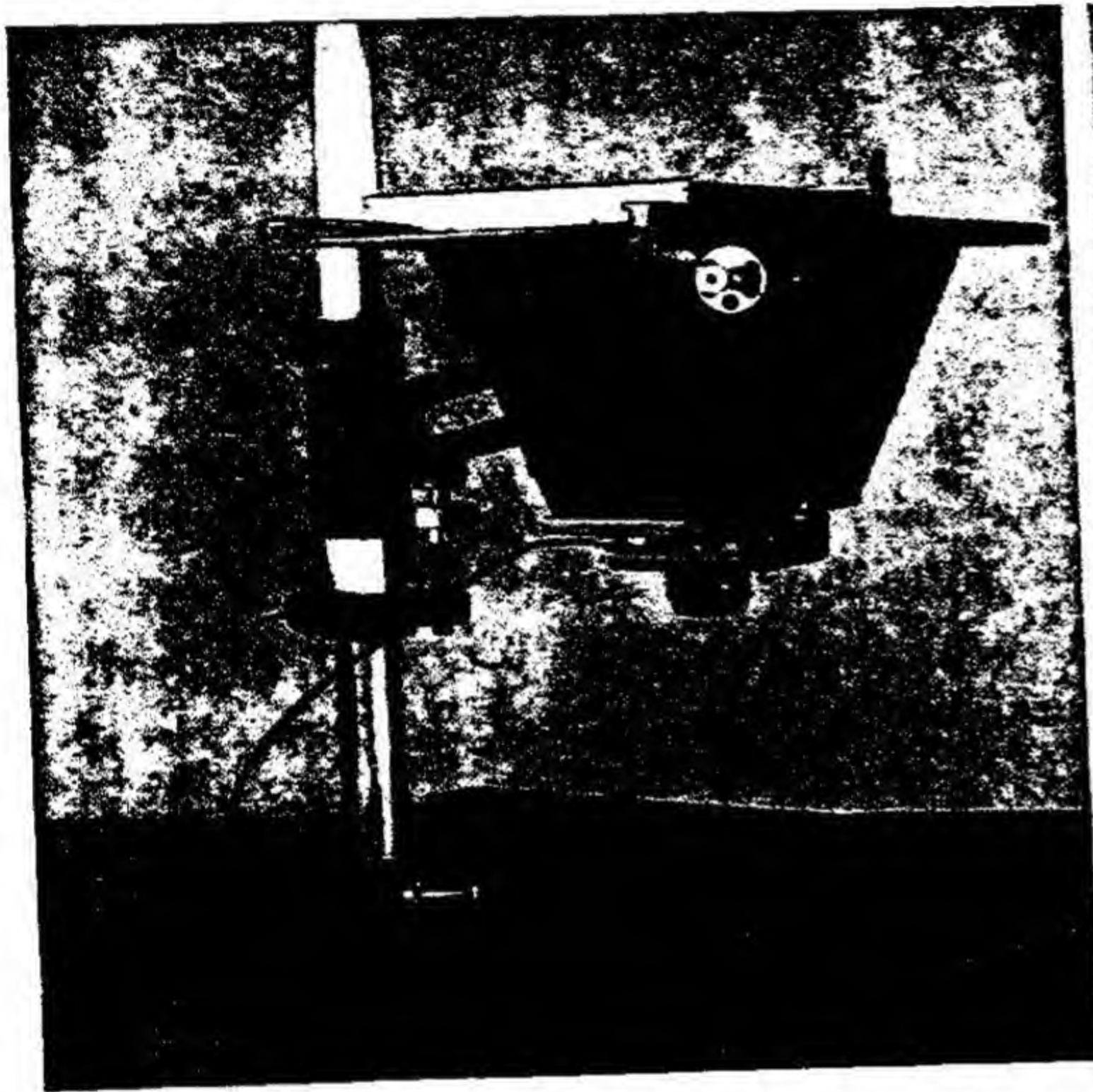


Fig. 138. Orthostereoscopic camera.

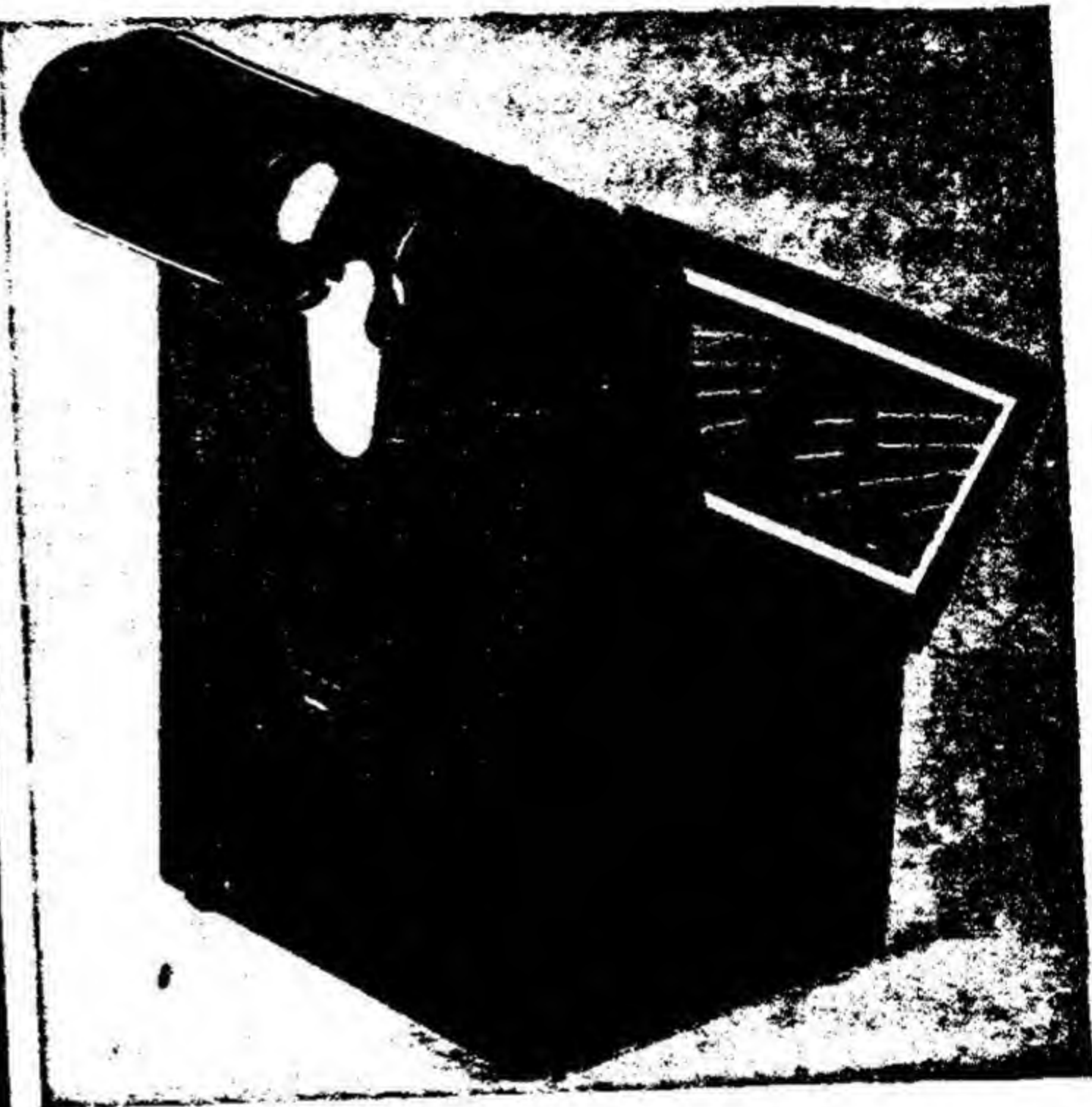


Fig. 139. Stereoscope.

suffice. The roll should be developed and placed on file. It is not necessary to make the transparencies until it is certain that the expert's testimony will be required at the trial.

Other methods of stereoscopic photography are available for practical use. These differ mainly in the method by which the two images are separated. At present the *vectograph* method is enjoying a wide popularity. In the vectograph two slightly displaced images are produced on one print. The images differ in that they will reflect image-forming rays which are polarized at right angles to each other. When the print is viewed through polarizing glasses which are oriented in the proper direction, a different image is received by each eye with the desired stereoscopic effect.

## 6. PRINTING THE STEREOSCOPIC NEGATIVE

The essential condition for correctly viewing stereoscopic photographs is that the print made from the negative taken with the right lens be presented



to the right eye in viewing, and similarly the left print to the left eye. If this condition is not observed, a *pseudoscopic* view results. The pseudoscopic effect is a "reverse relief" effect; the rear planes appear to be near and the forward planes far, thus giving to some objects the appearance of being turned inside out. This effect is most pronounced in photographs of simple geometric designs such as polyhedra. In the case of ordinary objects the effect may be difficult to observe, because the observer's memory dictates the conventional impression.

The print, then, should be made so that the view presented to the right lens is on the right side of the print when it is being viewed by the eyes. To accomplish this, ordinarily it is necessary to transpose the right and left sides of the negative when printing. If the two views are on one negative, the right negative is printed on the left side of the paper and the left negative on the right side. The negative can be cut in two and printed or a printing frame devised so that the right side of the negative is printed on the left side of the paper. In some cameras designed specifically for stereoscopy no transposition is required in printing the negative. With the camera shown in Fig. 138 this is accomplished by shifting both plate and lens between exposures.

The printing of transparencies requires a technique varying with the type of camera used in making the negatives and the apparatus used for viewing the positive. With 35-mm cameras the manufacturer's directions supply the necessary information. It should be mentioned in passing that the stereoscopic effect is greatly enhanced in the transparency. In fact, the viewing of a single transparency provides an illusion of three dimensions which is absent in the paper print.

## 7. THE STEREOSCOPE

In order to examine a stereogram or stereoscopic print, it is necessary to view the right and left photograph with the right and left eye respectively. It is possible to train the eyes to do this, but only with considerable practice and without the comfort required for a careful examination. A viewing device or *stereoscope* is ordinarily used for this purpose. The most common type consists of an arrangement (Fig. 139) wherein each eye is presented with a converging lens and a prism device to alter the direction of the entering rays. The optics for the right and left eye are separated by a septum (Fig. 140). Prismatic lenses are also used in this type of instrument.

A similar device is used for viewing stereograms in the form of transparencies. The stereoscope in this case is lighttight on the sides and has a groundglass back to illuminate the film from the rear. The lenses provide a greater magnification since the film is usually of 35 mm size.

## 8. STEREOSCOPIC PHOTOMICROGRAPHY

The extremely limited depth of field in ordinary photomicrography makes it difficult to interpret the various details of the photograph. A three-dimensional view of the subject often clarifies the picture to a great extent even though



the sensation of relief is restricted to the region of the depth of field of the system. Most of the devices available for stereoscopic photomicrography are designed for low-power work. The instrument shown in Fig. 138 is applicable for magnifications up to 24X. A camera arrangement can be obtained for the Greenough binocular microscope. For magnifications greater than 80X, a single objective microscope is used. To obtain the necessary two views, several methods are applicable.

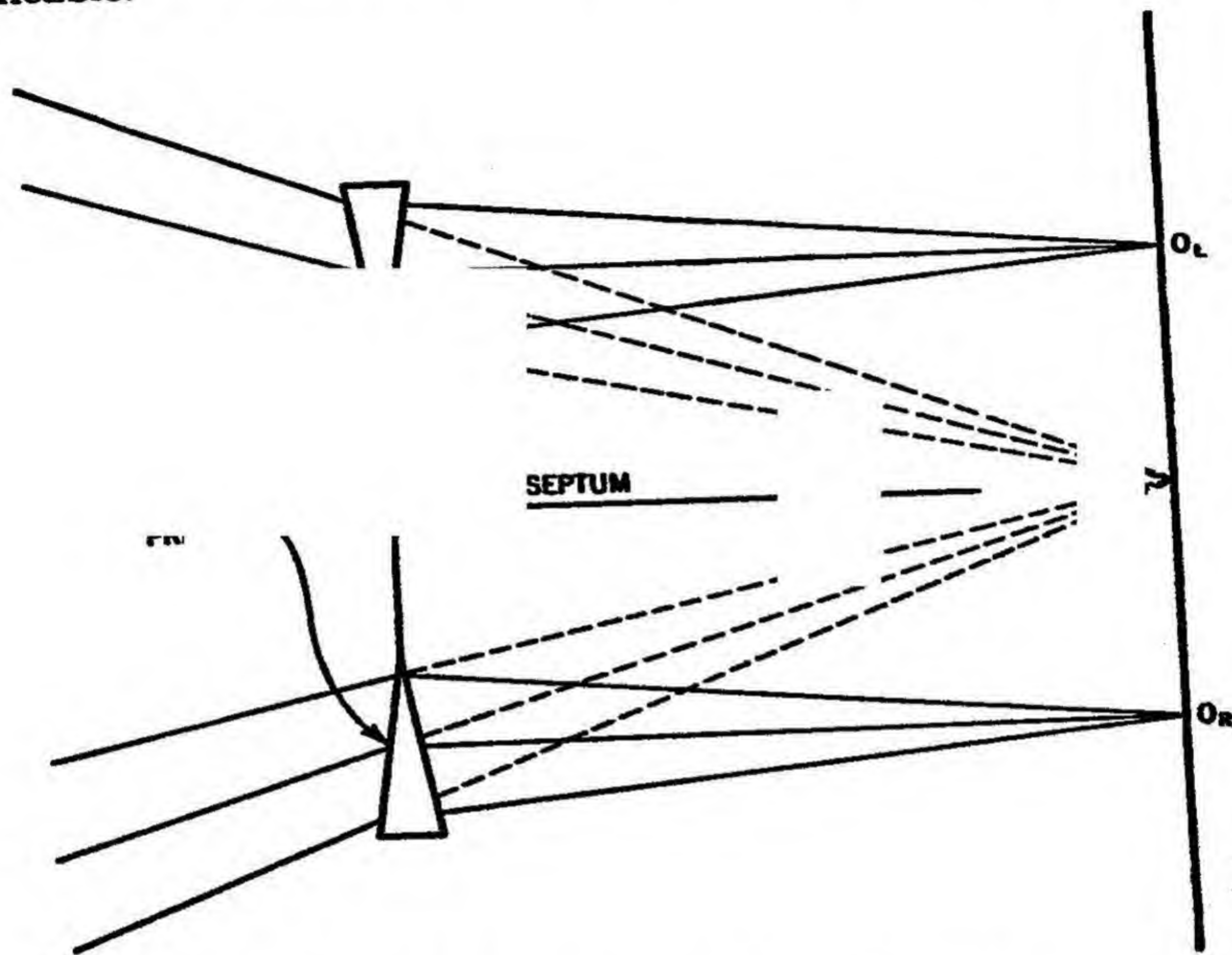


Fig. 140. Optical system of the stereoscope.

One method, similar to a camera arrangement previously mentioned, uses one-half of the objective for each view. There is a sufficient difference in angular view between the two halves of the objective to give a satisfactory photomicrostereograph. A circular diaphragm is placed over the back lens of the objective. The diaphragm has a smaller circular opening on one side (of a diameter equal to that of the diaphragm). The diaphragm is rotated through 180 degrees between exposures. A similar method consists in covering one-half of the image at the Ramsden circle or exit pupil of the eyepiece.

Another procedure is to move the specimen between exposures. The movement can be one of translation along the microscope stage or rotation about an axis parallel to the stage. A shift can be made either by means of the mechanical stage or by displacing the objective laterally by means of a centering objective holder. In conjunction with these methods it is advantageous to use a camera of such size that two views can be taken on one plate with a separation equal to the interpupillary distance, 62 mm or 2.5 inches. The prints, of course, are transposed in mounting.



## EXERCISES

1. Standing in front of a wall hold a pencil in front of one eye and close the other eye. Observe the difficulty in estimating the distance of the pencil from the wall. Notice the assistance provided in estimating the distance by the accommodation of the eye in focusing first on the pencil and then on the wall.

2. Using a 4 by 5 Speed Graphic or Graflex-type camera, make a pair of stereoscopic photographs by shifting the camera laterally through the interpupillary distance between exposures. Photograph an outdoor scene focusing on the hyperfocal plane. Use an  $f/22$  opening.

3. Repeat exercise 2 using a wide angle (3 in.) lens and a telephoto (13 in.) lens. Compare the three for limit of depth perception by viewing them through a stereoscope.

4. Using a 35-mm-type camera make a stereoscopic pair of photographs, either by shifting the camera or by means of the manufacturer's device, if available. Make a transparency of the pair, and view by means of an appropriate viewing device. Close one eye and observe the illusion of depth provided by single transparency.

5. With the 35-mm camera (on the same roll used in exercise 4, make a set of stereoscopic pairs of a piece of fractured glass to show the fit of two pieces. Photograph first with the pieces close together and then slightly separated. Make a similar set with a book of matches and a match torn from the book.

6. Make a photomicro-stereograph of some detail on the face of a coin. Photograph at low power — say, 25 or 50X. Use the method most suited to the apparatus available.

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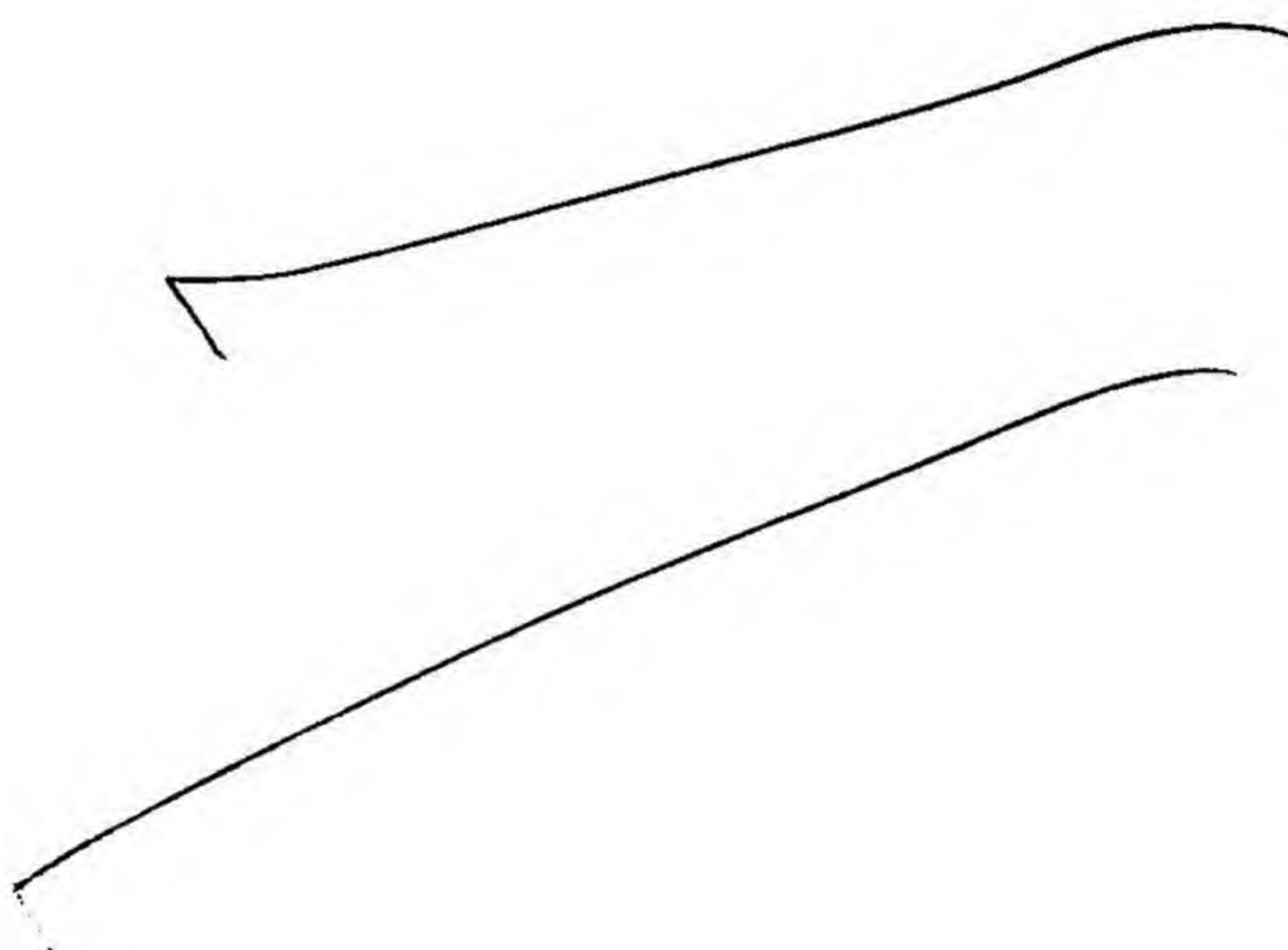




# PART E

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## PHYSICAL EXAMINATIONS









# CHAPTER 19

## *DIRECTION OF FORCE IN BROKEN WINDOWS*

Occasionally the successful investigation of a case depends upon the determination of the direction from which a bullet was fired or a blow was struck with reference to a pane of glass. A bullet hole in a car window, or a fractured window in a house may be explained by a witness in a manner which arouses suspicion. For example, in cases of a simulated burglary the window may have been broken from the inside instead of the outside. Again, the operator of a car in order to evade the consequences of a hit-and-run accident may drive the car some distance from the scene of the accident and abandon it in circumstances which would suggest that the car had been stolen. He may then claim that he was not operating the car at the time of the accident and point to the damaged window of the car for corroboration. Ordinarily he will not have broken the windows from the outside because of the danger of arousing the suspicion of possible witnesses.

It is the problem, then, of the laboratory investigator to determine the direction in which force was applied in breaking the window. The fractured glass will be similar in appearance to Fig. 141. The general pattern consists of continuous lines radiating from the point of impact and interrupted spirals concentric with the point of impact. Four phenomena should be observed in determining the direction of the blow: (a) cone fractures, (b) radial fractures, (c) spiral fractures, (d) rib and hackle marks on the cross-sectional surfaces.



**Fig. 141. Typical glass fracture.**



From a study of these phenomena it is possible to derive the following information:<sup>1</sup>

- (a) The direction of impact
- (b) The point of impact
- (c) The direction of travel of a given fracture
- (d) The nature of the shock causing the fracture — whether mechanical or thermal
- (e) The nature of the physical shock — whether a steady force or a sharp blow
- (f) The relative velocity of the fracture — whether slow or explosive
- (g) Conditions of strain in the glass — whether tempered or untempered

### 1. CONE FRACTURES<sup>2</sup>

If a metal ball or pebble is thrown through a windowpane a crater is formed on the opposite surface (opposite to the impact surface) of the glass (Fig. 142).



(a)



(b)

**Fig. 142. A fracture produced by a bullet: (a) entrance side; (b) cone fracture of exit side.**

This crater or cone fracture is caused by the great tension which is localized in the area owing to the indentation of the glass at that point. In the case of a cone fracture caused by a bullet additional information concerning the direction of impact is given by the distribution of the flaking about the crater. A shot fired perpendicular to a windowpane will give a crater of uniform flaking. If the shot is fired at an angle from the right, the left side of the glass will suffer more flaking than the right. Excessive flaking on the right side of a window would indicate a shot fired at an angle from the left. (Directions are taken from the point of view of the person shooting.)



## 2. RADIAL FRACTURES

The impulse of the bullet, stone, or instrument produces a flexure of the glass away from the point of impact. The surface opposite the impact is thrown into a state of tension which, because of the imperfect elasticity of glass, results in cracking along radial lines (Fig. 143). The cracking begins on the side oppo-



Fig. 143. Radial and spiral fractures.

site to the side of impact. This is due to the fact that the molecules are crowded together on the side of the blow and separated on the opposite side until the elastic limit is exceeded. On the opposite surface the fracture travels faster than on the impact surface.

## 3. SPIRAL FRACTURES<sup>3</sup>

This type of fracture is not always present in broken panes. It is most commonly found in laminated glass, such as that of automobile windows, probably because laminated glass is more flexible than ordinary sheet glass. Immediately after impact the glass rebounds and the compression stress on the impact surface changes to tension. The glass now begins to crack on the impact surface in the form of spirals which are interrupted by the radial fractures (Fig. 143). The fracture travels more rapidly on the impact surface than on the opposite surface. Tryhorn<sup>4</sup> and others describe the formation of spiral fractures in substantially the following manner. The cracking into radial lines divides the pane into a number of triangles or sectors of glass. These triangles are pushed out from the



point of impact by the initial impulse. This pushing out is resisted by the main body of the glass, which is fairly rigid. The effect of a torque is produced, and if the force is sufficient, the glass is now pushed in the opposite direction until again the limit of elasticity is exceeded and the glass begins to break on the side where the blow was struck. The cracking now takes place along quasi circles, concentric with the point of impact. The circles are interrupted by the con-

tinuous radial lines, which preceded them. Haward<sup>5</sup> has shown that the number of spiral patterns present in a fracture depends also upon the nature of the impinging force; a rapid, dynamic force produces more spiral patterns than a slow, relatively static force even though the total energy involved is the same in both cases.



Fig. 144. Cross-sectional view of a glass fracture showing rib marks.

#### 4. CROSS-SECTIONAL SURFACE

Figure 144 is a cross-sectional view of a glass fracture. Two general types of markings may be visible in the cross section — rib marks and hackle marks. Either or both of these marks may be absent in a fracture. Their shape and frequency depend upon the nature of the fracturing force and the glass.

##### Rib Marks

In Fig. 144 the lines which begin normal to one surface and curve asymptotically toward the other are called *rib marks*. These ribs indicate rest points in the forward movement of the fracture. The direction of movement of a fracture is such that the fracture approaches the rib mark on the concave side and leaves on the convex side. A series of ribs regularly produced indicates a slow fracture caused by a minimum force. Heavy rib marks spaced far apart indicate a region of tension. For our purposes the most significant aspect of rib marks is the fact that they begin normal to the surface on which the glass begins to crack and end tangential to the other surface. This phenomenon will be the chief criterion for

determining the impact surface in a glass fracture. The procedure therefore is to determine whether the fracture is radial or spiral. If the fracture is radial, the impact surface is the one which is tangent to the rib marks. If the fracture is spiral, the impact surface is the one which is at right angles to the rib marks. These latter conclusions follow from the facts that radial fractures first open on the side opposite to the impact surface, spiral fractures open on the impact surface, and rib marks are perpendicular to the side on which the fracture opens. In Fig. 145(a) the arrow indicates the direction of the force in a radial fracture and in Fig. 145(b) a spiral fracture.



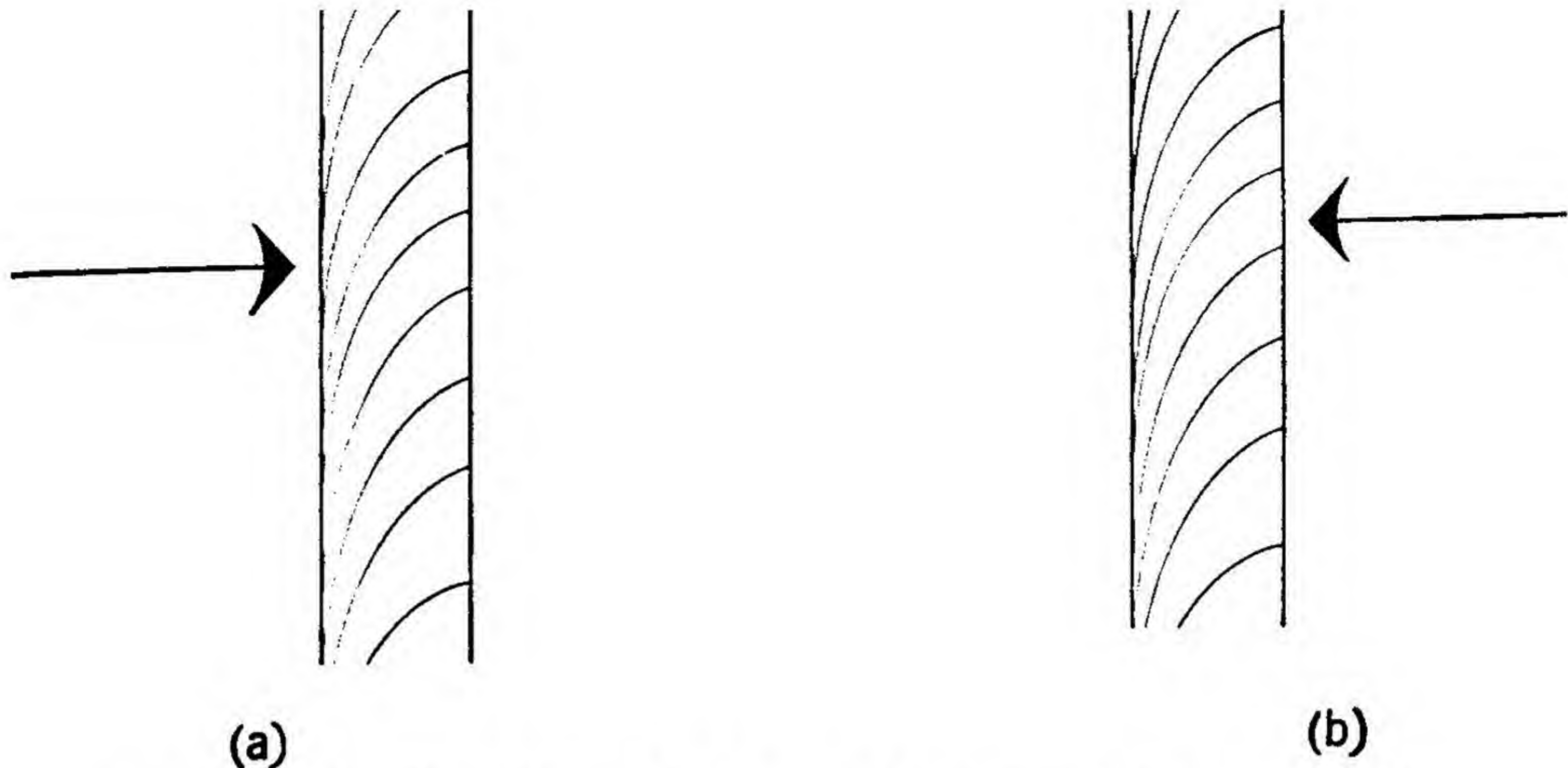


Fig. 145. Direction of impact in (a) radial fractures; (b) spiral fractures.

### Hackle Marks

The straight lines in Fig. 146 are called *hackle marks*. They run in the direction of movement of the fracture and are at right angles to the rib marks. Hackle marks indicate that the failure of the glass was due to a large shearing force, and that the rupture was sudden and explosive in nature. Since these marks run through the ribs at right angles they offer an additional aid in determining the impact surface, particularly in those cases where hackle marks are present in the absence of ribs.

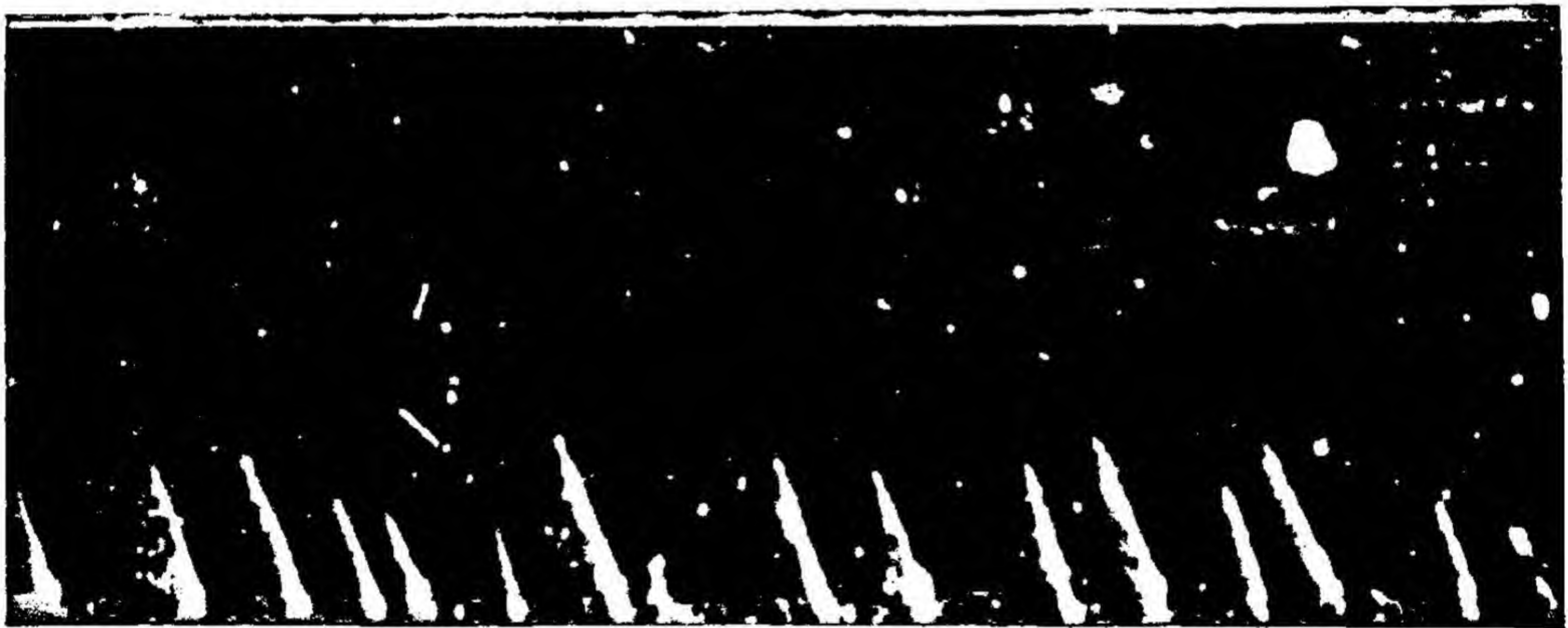


Fig. 146. Hackle marks (10X).

### Photographing the Cross-sectional Surface

In presenting court testimony concerning glass fractures, an enlarged photograph of the cross-sectional surface is of great value. A photomicrograph of the surface at a 6X enlargement is satisfactory. The illumination should be oblique to emphasize the rib marks. Another method, described by Oughton,<sup>6</sup> produces



a shadowgraph by means of light transmitted through the glass surface to the film. The glass specimen should be approximately one-quarter inch thick.

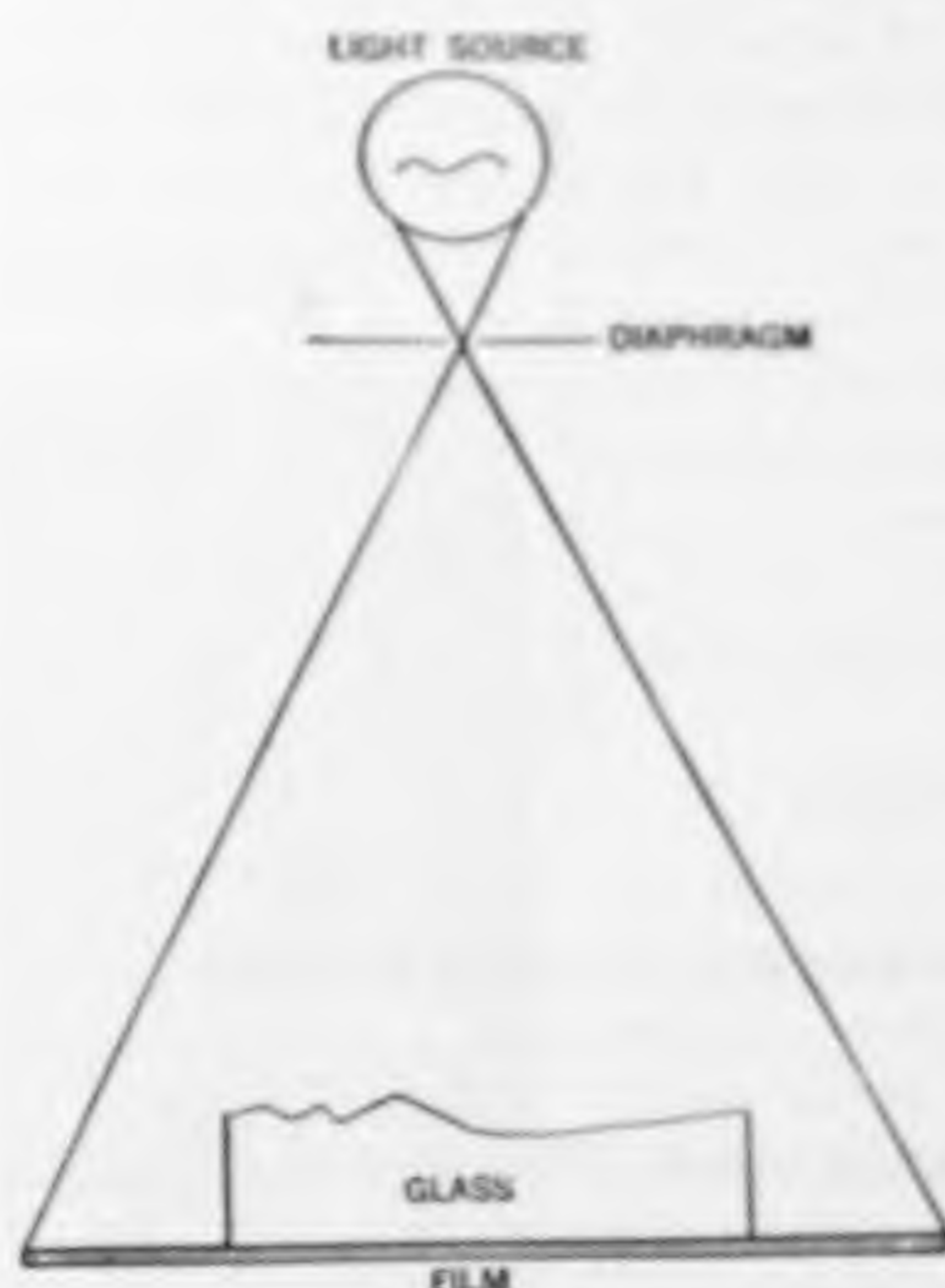


Fig. 147. Shadowgraph method for photographing the cross-sectional surface.

The opposite surface is ground and polished. The specimen is placed on the film with the polished side down. A point source of light is placed directly above the glass (Fig. 147). The exposure must, of course, be made in a darkened room.

## 5. SAFETY GLASS

This kind of glass, which is most commonly found in automobiles, does not shatter when struck sharply, and hence is excellent for studying radial and spiral fractures. We have seen that the radial cracks begin from the side opposite to the side of impact, and the spiral fractures begin from the side of impact. Frequently in the case of safety glass the cracking is not complete; i.e., the radial cracks do not extend to the side of impact and the spiral cracks do not extend to the other side. In addition to the cross-sectional examinations, then, an additional test for safety glass may be made by running the finger-

nail along the surface of the glass. If the radial cracks are felt and not the spiral, that side is not the side of impact; if the spiral cracks are felt and not the radial, it is the side of impact. In the absence of spiral fractures, the fact that the radial fracture is felt on one side and not on the other is significant.

Another test which can be applied to safety glass depends upon its property of bending instead of shattering when struck. The side on which the glass is struck will be found to be concave. This can be tested by laying a long straight-edge ruler on the glass and observing the space between the ruler and the glass.

## 6. PROCEDURE IN EXAMINING A WINDOW

If the window has been struck but the pieces have remained in position in the window frame, the glass should be examined for cone, radial, and spiral fractures. The window can then be removed to the laboratory and the cross-sectional surfaces examined.

If the window has been shattered and the pieces are lying on the ground, a different procedure is necessary, especially if the glass remaining in the window frame is not cracked. The distribution of the glass on the ground should first be noted. The next step then is to piece the glass together. If the window is exposed to the weather, the outside of the glass will bear characteristic dirt, grime, or



water spots, and may thus be distinguished from the inside. Moreover, in piecing the glass together the sides of the glass can be distinguished by the relation of the pieces on the ground to the pieces remaining in the window frame. The cross-sectional surface of the reassembled pieces may now be studied and the direction of the blow determined.

With ordinary window glass it will be found that the fractures are usually complete; i.e., the crack may be felt on both sides. Hence the test previously recommended for safety glass cannot be applied to ordinary glass.

When there are two bullet holes in a window, one from each side, the problem of priority may arise: which bullet went through the window first? This question may be important in determining the aggressor in some act of violence. To make this determination the fractures caused by each bullet must be examined. It will be found that the fractures caused by the first bullet will be complete, especially the radial cracks; whereas the fractures from the second bullet will be interrupted and end-stopped at points where they intersect those from the first bullet. In Fig. 148 a few of these interrupted lines are visible.



Fig. 148. Two bullet holes in glass. The bullet hole on the left was made first.

## EXERCISES

1. To produce cone fractures, fire a revolver through panes of window glass in the following manner: (1) Perpendicular to the glass; (2) at an angle of  $45^\circ$  to the right; (3) at an angle of  $45^\circ$  to the left. Observe the cones in each trial.

2. Using a ball peen hammer on a pane of glass strike a blow so that a pattern of radial and spiral fractures is produced. Examine the cross-sectional surfaces of a radial and a spiral fracture. Determine the direction of the blow from this examination.



3. Repeat exercise 1 with a pane of safety glass. Examine the glass to see if the fractures are "through" on both sides. Test for concavity.

4. Fire two shots, spacing them about a foot apart, in a pane of glass. Determine which shot was fired first.

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# CHAPTER 20

## *GAMBLING MACHINES, MARKED CARDS, AND ALTERED DICE*

### **1. GAMBLING MACHINES**

A gambling machine, from the point of view of the scientific investigator, is a mechanical apparatus which is intended to reward the user according to the laws of chance or the degree of skill which he exercises. There are two important classes into which gambling machines may be divided: (a) slot machines and (b) pinball machines. In the slot machine the rewards should depend upon chance alone; in the pinball machine they will depend upon skill as well as chance. Naturally, these machines must return to their owners a "reasonable" profit. If the machine returns an excessive percentage, it is considered to be "rigged."

In the investigation of gambling machines the nature of the inquiry will depend upon the laws of the community concerned. Some communities permit gambling devices provided they are honest, i.e., they offer a fair return to the player. An inquiry concerned with a machine in such a community would endeavor to determine if the machine was so arranged that the owner could control the awards by tampering with the apparatus. In other communities games of skill only are permitted and the gambling machine may be legal if the player is rewarded according to his skill. In such a community an investigation of a machine, such as the pinball type, would be made to show that pure chance and not skill determines the awards.

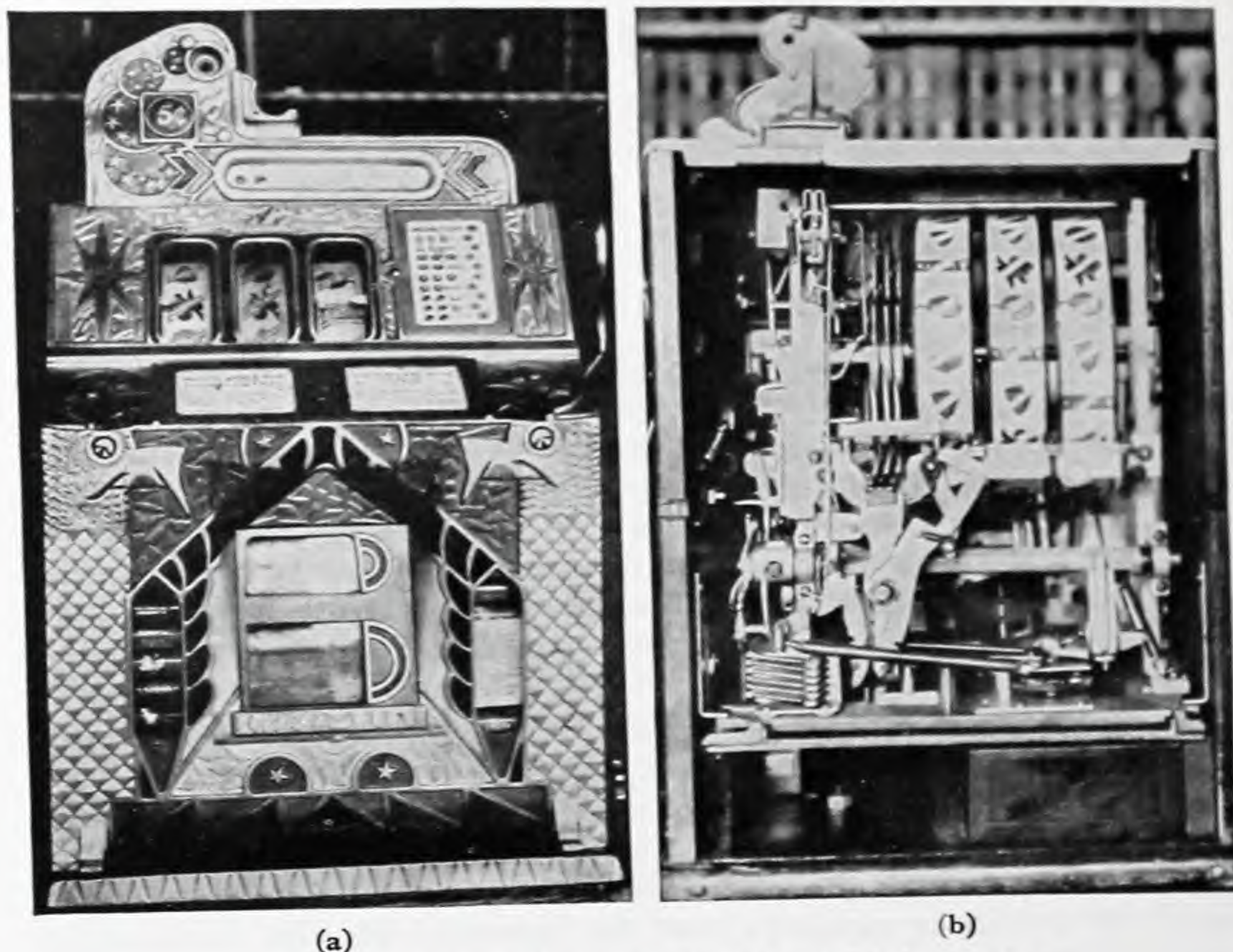
#### **Slot Machines**

A typical slot machine is shown in Fig. 149. A coin is inserted in the slot, the lever on the right-hand side is pulled down and three wheels revolve. Facing the player, the wheels show various symbols such as illustrations of fruits. When the wheels come to a stop, three symbols are on a line facing the player. These symbols determine the number of tokens or coins which are returned to the player at an opening in the base of the machine. In many machines an auxiliary device delivers a package of candy to the player in order



that the machine may be termed a vending device rather than a gambling machine.

The mechanism of this type of machine is too complex to be described here. This complexity is chiefly due to the ingenuity employed in protecting the machine from being cheated. When a coin is inserted into the slot it can follow one of three paths: it can follow the pay-out tube, go into the jack-pot, or be deposited in the coin box. The pay-out tube delivers coins or slugs when winning



**Fig. 149. A slot machine: (a) front view; (b) the interior.**

combinations appear on the wheels. One combination releases the jack-pot, which is the maximum reward. The coin box retains the house winnings and can be opened only by the owner.

In an investigation of a slot machine it is not necessary to make an exhaustive study of the mechanism. A statistical analysis is usually sufficient. A series of 1000 or more plays should suffice to show the percentage of earnings which go to the machine and to establish the frequency with which certain combinations turn up. If it is suspected that the machine is rigged, it may be necessary to study the mechanism (although the statistical analysis would reveal such an arrangement). For example, it is possible to adjust the mechanism so that the three symbols which indicate the jack-pot cannot line up. By manipulating a



set of levers at the back of the mechanism it is possible to release the jack-pot or the pay-out tube when the operating lever is pulled. Finally, the machine can be adjusted so that certain of the symbols on each wheel do not turn up, thereby greatly decreasing the players' chances.

To calculate the mathematical probability of a certain set of symbols showing, we must assume that the probabilities for the symbols on a given wheel are equally likely. Thus if there are four lemons on a wheel of twenty symbols, the probability of a lemon turning up is  $4/20$ . If each wheel has four lemons, then the probability of turning up three lemons on one line is  $(4/20)^3$  or  $1/125$  (see Chap. 46). If there is but one jack-pot symbol on each wheel, the probability of turning up the three symbols is  $(1/20)^3 = 1/8000$ . A set of such probabilities for the various combinations can be computed in this manner and compared with the results of the statistical analysis. Serious discrepancies between the calculated probability and the statistical result indicate rigging of the machine. The methods of Chapter 5 should be used in determining a statistically reliable difference.

### Pinball Games

The second class of machine with which we are concerned combines theoretically the element of skill with that of chance. Figure 150 is a photograph of a pinball game, a representative machine of this class. On the insertion of a coin in a slot a number of balls are delivered to the player. A spring plunger at the lower right-hand corner is used to project each ball to the top of the table. The table is inclined so that the ball will roll down into a hole or other receptacle. An elaborate electrical arrangement records the score according to the value assigned to the hole in which the ball comes to rest. Machines are variously designed with complex arrangements of obstacles, pins, and recoil springs which affect the path of the ball. If the total score for ten balls exceeds a certain value the player is rewarded.



Fig. 150. Pin ball machine.



The owners of machines of this type usually maintain that they are not gambling apparatus because the score depends upon the degree of skill exercised by the player. This is an important point in law. In some states it has been decided that the legality of a game played with such a machine will depend upon the degree to which the element of skill determines the score. Hence an investigation of a case involving machines of this type should have two aims: (1) To form an estimate of the chance of obtaining a winning score in playing the machine, and (2) to determine to what extent the score is affected by the skill of the players.

To conduct such an investigation it is necessary to play the machine a great number of times. The dynamical situation which determines the trajectory and final resting place of a played ball is so complex in nature that *a priori* conclusions reached by a study of the machinery have no great value. The most that can be expected from examining the machinery is some insight into the way in which the machine can be adjusted to control the relative ease or difficulty of obtaining high scores.

In gathering statistical data on a machine a number of players should be employed to operate the machine. In recording scores for any given machine the data should include not only the final score of each game but also the number of times a ball fell into each hole. Four or five players should make several thousand plays in order to determine whether or not skill can be developed by practice. A learning curve should be made for each of the players. These curves should be compared with typical learning curves in order to determine whether or not any increase in the scores of a player is the result of learning improvement or of mere chance distribution. The probable error of the data should also be considered before any conclusion is drawn.

Several thousand random plays are also needed in order to determine the probability of certain scores by mere chance. These data can be acquired by covering the machine with a cloth and requesting various people to play the machine in this condition. The scores obtained by random play should be compared with those in which the players' skill was employed. Again, the methods of Chapter 5 should be used to determine the presence of a statistically reliable difference. The absence of a statistically reliable difference would indicate that skill had no effect on the scores.

## 2. MARKED CARDS

In communities where gambling is permitted under the law, the use of marked cards is a relatively serious offense because of the consequences (assault, stabbing, or shooting) that frequently follow upon their discovery by players in the game. Cases involving marked cards are usually of a technical nature, requiring a laboratory examination of the evidence. In order to treat these cases adequately, the laboratory should have a collection of catalogues of the companies that manufacture marked cards. A collection of samples of the popular brands of such cards will also be of assistance. In general, cards may be marked



for identification from the back either in the course of manufacture or at a later date by the card sharp who may do this in preparation for a game or during the game. The following discussion will elaborate upon the methods and variations used in marking cards.

### Marking in Manufacture

(a) *READERS*. Cards marked in manufacture are usually called *readers* in the trade. The design on the back of the card is altered according to some scheme so that the identity is revealed to a person privy to the scheme. The backs of most decks of cards bear a complicated geometrical design. By a slight alteration in the geometry or in the shading of the design the suit and number of the card are made known. The design of these decks is often that of one of the popular brands manufactured by legitimate concerns. An operator using decks marked in this manner sometimes wears eye-glasses which will magnify suitably. Figure 151 shows a set of photographs of a deck marked for the game of "Blackjack" or "21."

(b) *STRIPPERS*. In these decks certain of the cards are trimmed slightly, so that, for example, when the cards are cut (divided), the cut is always made for a longer card, leaving the shorter card on top of the remaining pile. The cards may be trimmed or shaved at the ends, sides or corners. The sides of the cards are sometimes made slightly concave or convex. Any of these arrangements will give a skilled operator control of certain cards in the deck. The cards which are affected are chosen for the

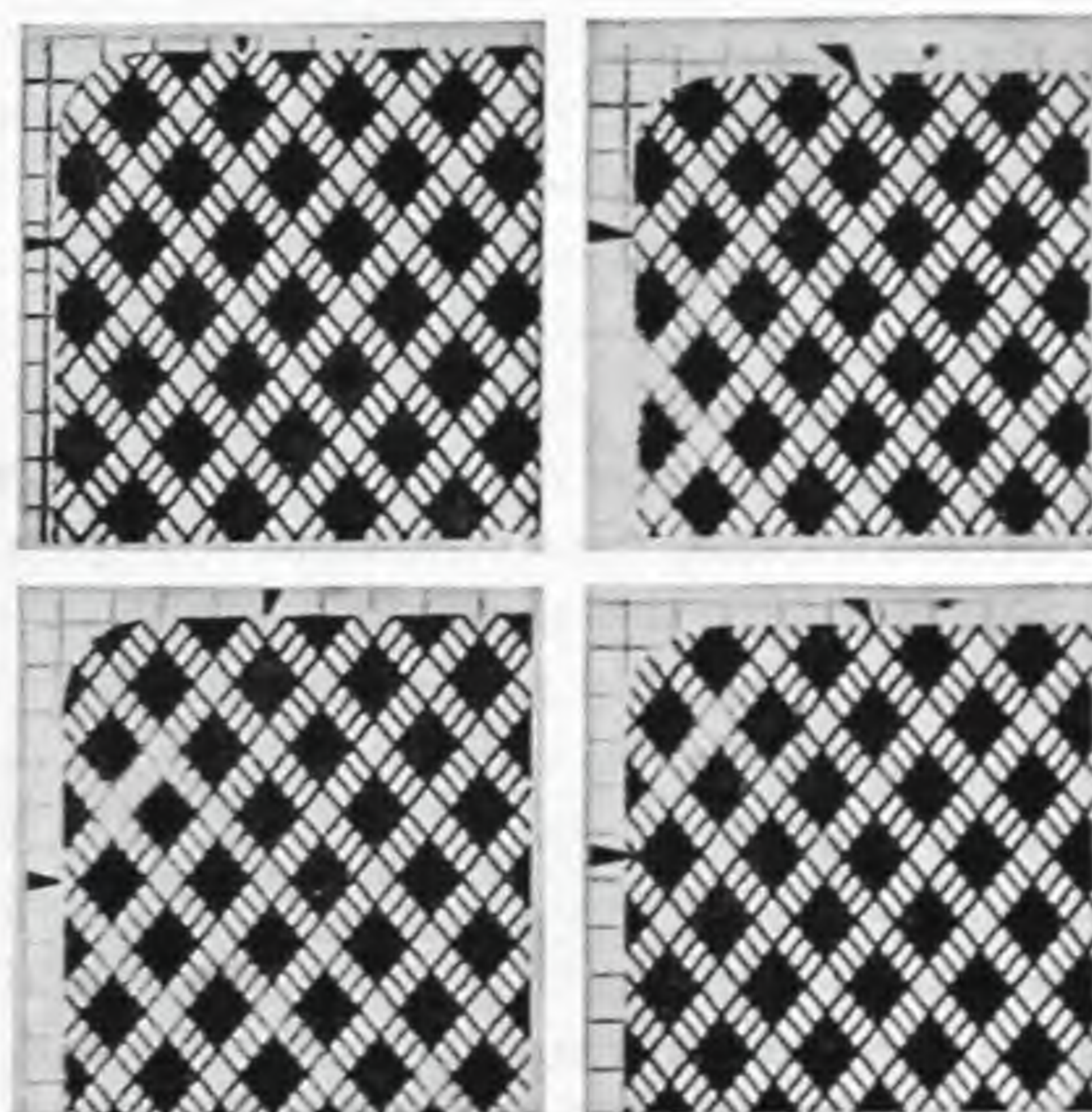


Fig. 151. Marked cards.

purpose of a particular game: three aces for poker; seven-up for whist; two red jacks and one red ace for euchre; deuce, eight, ten of spades, and ten of diamonds for casino. Strippers are also made in combination with readers.

The methods of detecting trimmed cards are simple. The first step should be the actual cutting of the cards a number of times and noting any recurring cards. Secondly, a precision measurement should be made of the length and width of representative samples of the cards. A knife-edge square should then be used to detect any concavity or convexity. In preparing such evidence for court presentation, enlarged photographs of standard size cards and altered cards from the same deck should be made with a ruler included in the field of view.

(c) *LUMINOUS READERS*. A large number inscribed on the backs of these cards is made invisible by color camouflage. These numbers are printed



in one color, which is imbedded in other colors so that it is not discernible to the naked eye. When observed, however, through a filter, the number is clearly seen. For example, if the number is green and the background predominantly red, the number will appear white against a black background through a green filter. Tinted glasses or a celluloid eyeshade can serve as a filter. The most common form of filter is a pair of green sunglasses or a green eyeshade such as was formerly used by clerical workers. Obviously, this type of marked card is detected by examining them with a series of filters such as are used in photography. The Eastman Kodak Filter Test Chart, or similar filter card, is satisfactory for this purpose.

*A GAME.* The card cheat also prepares his line and block inks are used to alter the inks are made and blue are applied with a ballpoint pen. For any "shadow" work, a less expensive type of ink is used. Cards can also be marked or shaded by a skilled operator. After a deck has been prepared by any of these methods, it can be placed in a fresh glassine wrapper and enclosed in the original cover.

(b) *DURING THE GAME.* Although the deck introduced into a game is unmarked and perfectly fair, it is possible for an enterprising player to mark various cards while dealing them or otherwise handling them. This kind of marking is usually accomplished by rubbing a substance on the back of a card or by pricking the card with a small punch. In the first method a small box of wax or daub is concealed in the clothing in such a position that a finger can readily be placed on it without exciting suspicion. The finger is then rubbed on the card. The card is thereafter identifiable by the eye or the touch. In the second method a small sharp punch is attached to the underside of the thumb or hand by means of adhesive tape.

The most common method of marking cards during a game is by means of the *crimp*. This is accomplished by pressing the nail of the thumb against the cards, thus creating a ridge. In the hands of an expert, the cards so crimped can be located at will by touch or sight.

### 3. ALTERED DICE

Another scheme for removing the element of chance from gambling is the use of altered dice. A dice game differs, however, from a card game in that the player frequently has no opportunity to touch the dice while he is betting. Thus the caster may shift from fair to altered dice and back again without permitting the victim to study the dice. There are many ways in which dice may be altered so that the probability that certain numbers will turn up when the dice are rolled is greatly increased. Among the types frequently employed are the following:



### Edge-work Dice

In this type certain edges are altered to favor specific numbers in the rolling. Among the common alterations are the following:

**RAISED EDGE.** By applying a flatiron to two opposite sides the edges can be raised slightly, so that certain faces will be greater in area.

**CUT EDGE.** Some dice, instead of the usual six faces, possess narrow connecting faces which are at an angle of about  $45^\circ$  with the main faces. By altering this angle on certain sides the roll of the dice is affected.

**SERRATED EDGE.** Cuts are made on the edge to alter the roll.

### Shaped Dice

In this type the form of the die is no longer that of a perfect cube. By altering certain dimensions, a bias is introduced in favor of certain numbers. This may be done by not only making the distance between one set of faces shorter than that between another set, as in the case of *bricks* or *flats*, but also by tapering the die so that it has the form of a truncated prism. Another method of shaping is to bevel one side of the die (Fig. 152).

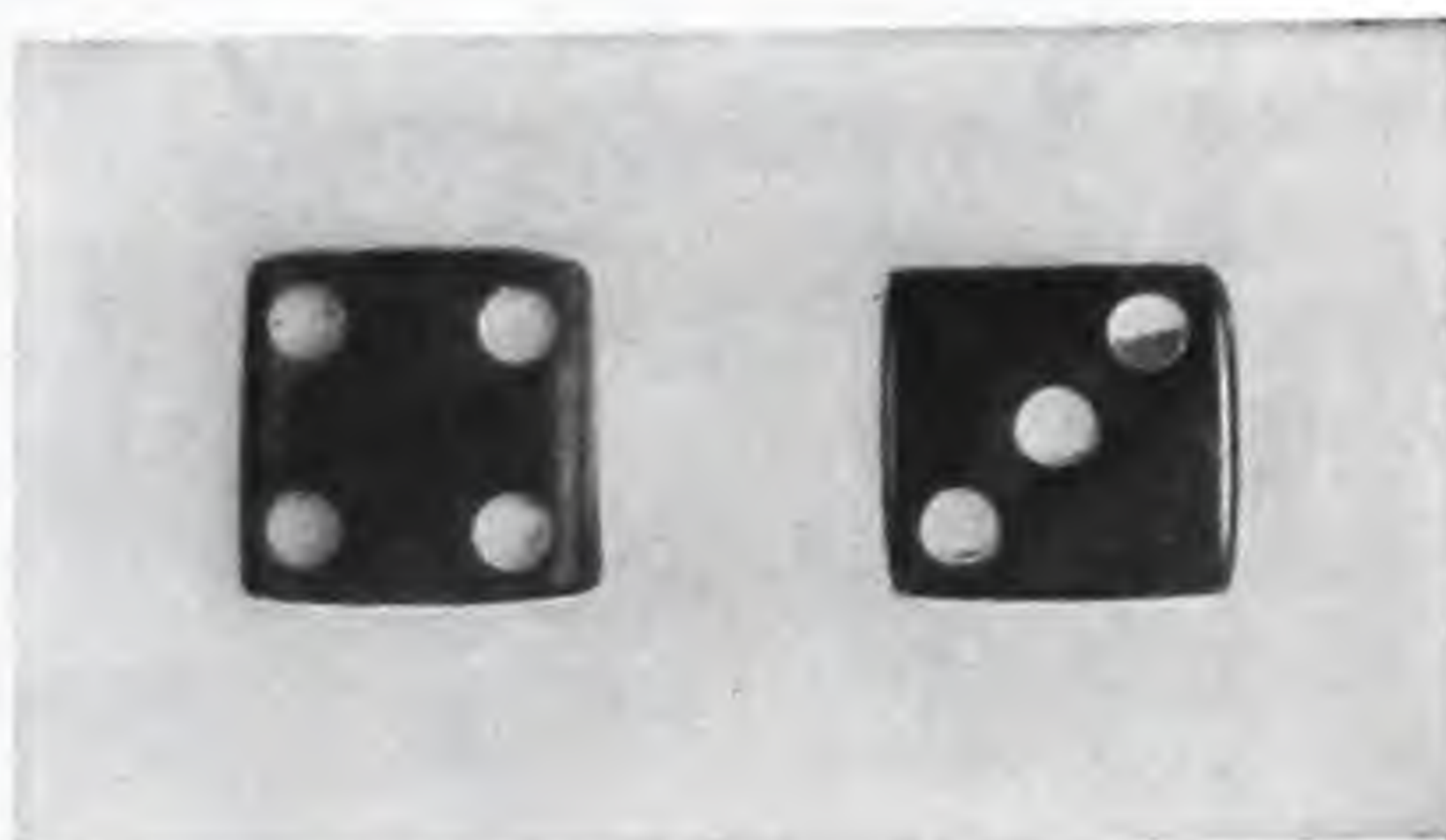


Fig. 152. Shaped dice.

### Capped Dice

A special cap can be placed over one side of the die so that its elasticity is greater on one side than on the others. Such dice are usually used on tables with billard cloth covering (Fig. 153).

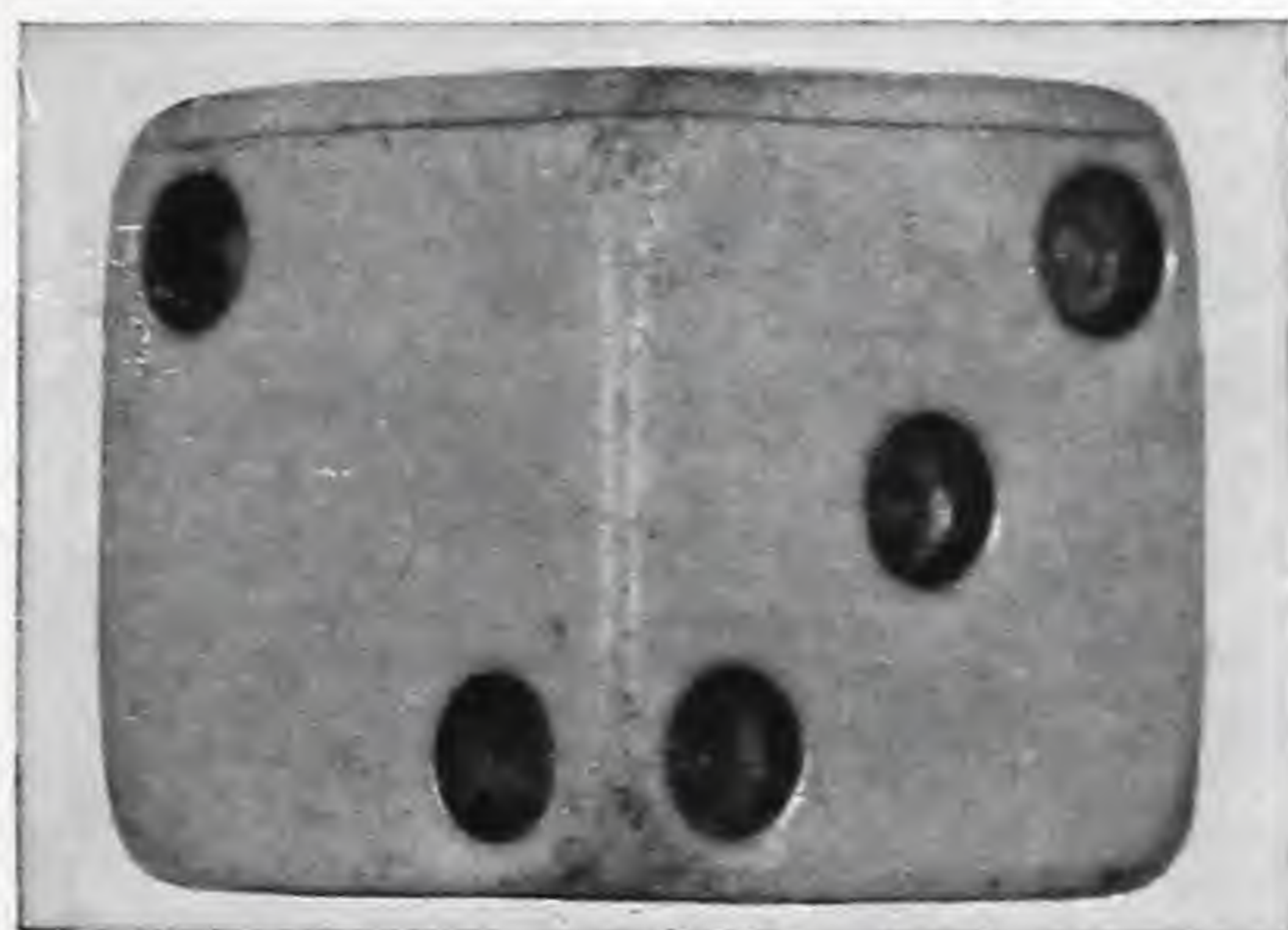


Fig. 153. A capped die.

### Raised Point

The rolling of the dice can be affected by a slight protuberance on the center of one of the faces. Another technique employed is that of raising the spots slightly.

### Filled Dice

Displacing the center of gravity by concealed weights will also increase the probability for certain numbers.

The method usually employed is to

conceal the additional weight beneath the spots bordering one edge of the die. Gold, copper, amalgam, mercury, steel, or lead may be concealed beneath the paint (Fig. 154). It is possible also to use in the paint heavy ingredients such as



lead carbonate, lead oxide, or mercuric sulfide. Fluid, paste, and powder are sold for weighting dice. More commonly the dice are manufactured specifically for the purpose. The appearance of the dice gives no indication of their altered character. Filled dice may be made either of opaque or transparent materials.



Fig. 154. Radiograph of filled dice.

Spots of various kinds (concave, flush, bird's-eye) may conceal weighting material.

The center of gravity can also be displaced by hollowing out the interior on one side; these dice are called *floats*.

#### **"Electric" Dice**

Another method of controlling dice is to load them with a ferromagnetic metal and to conduct the game on a table which conceals an electromagnet. By means of a button or other device the operator is able to close the circuit while the dice are rolling and thus bring them to rest with the loaded sides down. The load used is very light. For example, small circular grids of steel wire sometimes are inserted beneath the spots.

### **4. PROCEDURE OF EXAMINATION**

#### **Measurements**

Using a micrometer caliper, measurements should be taken of each dimension of both dice. A knife-edge square should be applied to each die to see if it is out of square in any way. If the die appears to be shaped irregularly in any



way, the measurements should be repeated, readings being made on different parts of the same faces. The methods of Chapter 5 should be applied in analyzing the data (see especially p. 46). The dice should be examined for beveling, raised edges and spots, convex edges, and other irregularities.

### **Displacement of Center of Gravity**

Filled dice can be detected by immersion in a liquid of greater density. To achieve equilibrium when floating in such a liquid, the die will assume a position in which the heavier side is downward. The die should be dropped into the liquid a number of times until the existence of a suspected tendency is verified. Weighted dice can be detected also by the use of a balancing caliper. The die is placed in the caliper so that the jaws hold the die by two corners. If the die is weighted, it will balance in only one position.

### **Weight**

Each die should be weighed on a sensitive chemical balance. Samples of similar dice should be procured and a comparison made of the weights. Differences of about 0.5 gram or more should be regarded as suspicious. The weight of a die is in the region of five or six grams.

### **Microscopic Examination**

A low-power binocular microscope should be used to examine dice critically. Each edge should be inspected for curving, serration, cuts, elevations, etc. The sides should be examined for evidence of capping. Paste, powder, or other substance on one side of the die should be regarded with suspicion. The spots should be examined for differences in paint, scratches, and other indications of alterations.

### **Magnetic Field**

By placing a strong magnet near the dice, concealed ferromagnetic metals can be detected.

### **Ultraviolet Examination**

Under the ultraviolet lamp in a darkroom, differences in fluorescence may be observed. Differences in paint or the presence of foreign powder, paste, or other substance may be detected in this way.

### **X-ray Examination**

A radiograph will reveal the presence of any metal or other foreign substance of considerably greater density than ordinary dice materials. Figure 154 shows radiographs of filled dice. An exposure of 8 to 12 seconds at 22 to 26 inches, using 60 kv and 10 ma will suffice. Commercial ortho film in a regular film holder may be used. Any x-ray film would also prove satisfactory for this simple subject. No intensifying screens are necessary.



### Chemical Examination

If it is found that the dice are weighted in any manner, chemical analysis of the substance used is in order. The probable nature of the weighting materials has been discussed previously. Because of the small quantities of weighting material present, chemical analysis is sometimes difficult. Spectrography is admirably suited to such an analysis and should be applied where the facilities are available.

### Laws of Probability

To detect any prejudice toward certain numbers, a statistical analysis of a great number of rolls will prove helpful. If the experiment is conducted with a single die, the probability of turning up any number is obviously one out of six. If two dice are used the probabilities are given in Table 8.

TABLE 8

NUMBER	2	3	4	5	6	7	8	9	10	11	12
PROBABILITY	$\frac{1}{36}$	$\frac{2}{36}$	$\frac{3}{36}$	$\frac{4}{36}$	$\frac{5}{36}$	$\frac{6}{36}$	$\frac{5}{36}$	$\frac{4}{36}$	$\frac{3}{36}$	$\frac{2}{36}$	$\frac{1}{36}$

(These conclusions are derived in Chap. 45.)

The suspected dice should be rolled a great number of times and the results recorded in a frequency table. These values should be compared with those of Table 8 to determine whether there is a statistically reliable difference.

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# CHAPTER 21

## ULTRAVIOLET AND INFRA-RED EXAMINATIONS\*

### ULTRAVIOLET EXAMINATIONS

#### 1. NATURE OF ULTRAVIOLET LIGHT

That section of the electromagnetic spectrum between 136 and 4000 Å is called the *ultraviolet region*. This range includes five octaves, in contrast to the single octave of visible rays from 4500 to 8000 Å. The ultraviolet rays lie between x-rays and visible rays; they are longer than the former and shorter than the latter. Solar radiation includes a portion of the longer ultraviolet rays. As in the case of other radiations, these rays can be both beneficial and harmful. Ultraviolet light can be temporarily very harmful to the eyes. Snow blindness is the result of the reflection of these rays by the snow. In working extensively with this light, the eyes should be protected by suitably colored glasses.

#### 2. USE OF ULTRAVIOLET LIGHT

Ultraviolet light impinging on a substance may be absorbed. In some substances the energy which is absorbed results in the displacement of an electron from its normal orbit in the atom. In returning to its orbit the electron may give up its energy in the form of visible light. This phenomenon is known as *photoluminescence*. If the substance is visible after the source of energy is removed, the phenomenon is called *phosphorescence*; if the substance ceases to be visible, it is called *fluorescence*. The appearance of an object when fluorescing under ultraviolet light may be surprisingly different from that in ordinary light. It is this phenomenon which forms the basis of the use of ultraviolet light in the police laboratory. Invisible writings, stains, differences in ink, paper, cloth, etc., are often discernible in ultraviolet light because of the contrast produced by fluorescence. These applications will be discussed in detail later.

\* See Chap. 17 for techniques of photography in ultraviolet and infra-red light.



### 3. ULTRAVIOLET SOURCES

The most common source of ultraviolet light is the sun. The visible portion may be filtered out and fluorescent effects made observable, if the object is in dark with respect to other light. Iron arcs and carbon arcs also are sources of ultraviolet radiation, especially in the short-wave region. In laboratory work, however, the quartz mercury-vapor lamp is the most satisfactory source of ultraviolet light for the purposes of criminalistics. Its spectrum range extends



Fig. 155. Hanovia ultraviolet lamp.



Fig. 156. Portable ultraviolet lamp for fluorescent examinations.

from 1800 to 14,000 Å, but most of the radiation is in the region below 4500 Å. Quartz glass is used because ordinary glass does not transmit ultraviolet. The spectrum range can be limited by using quartz glass of suitable color as a filter.

The mercury-vapor lamp should be installed in a room which can be made completely dark. The room should be equipped with facilities for ultraviolet photography in the dark. A Cooper Hewitt or Hanovia type lamp (Fig. 155) may be used where examinations or photographs are made in different regions



of the ultraviolet, requiring various filters. To eliminate visible light, black glass filters of a nickel-cobalt type are used. An excellent portable unit for fluorescent examination is shown in Fig. 156.

#### 4. EXAMINATIONS BY FLUORESCENCE

One of the important uses of the fluorescence phenomenon is that of preliminary examination of substances. A considerable literature has arisen on this subject. The literature is (in the field of criminalistics) usually merely descriptive — some substances fluoresce, others do not. The color of fluorescence is used in distinguishing substances. For example, one finds that two lipstick stains appearing the same in ordinary light may fluoresce quite differently. Our treatment of the use of ultraviolet radiation in criminalistics will not be fortified by any theoretical reasoning; we shall merely describe certain observations concerning the fluorescence of objects which the investigator is frequently called upon to examine.

##### Stains

In rape cases garments are usually submitted to the laboratory for an examination to determine the presence of semen stains. The garment is placed under the ultraviolet lamp and spots which fluoresce are ringed with colored crayon (Fig. 157). These spots are then tested for the presence of spermatozoa. It will be found that many kinds of stains fluoresce, chief among which is the urine stain. Urine has a yellowish fluorescence; semen appears whitish. The ultraviolet examination is employed merely to limit the search, and has been vastly overrated for its detective properties in the literature of this subject. In general, no conclusions are reached concerning the nature of unknown stains by this means alone.

##### Glass

When it is necessary to compare two samples of glass, such as the glass found at the scene of a motor vehicle accident, and the glass of a suspected car, a preliminary ultraviolet examination should be made. If only one sample fluoresces, it usually is significant of a difference.

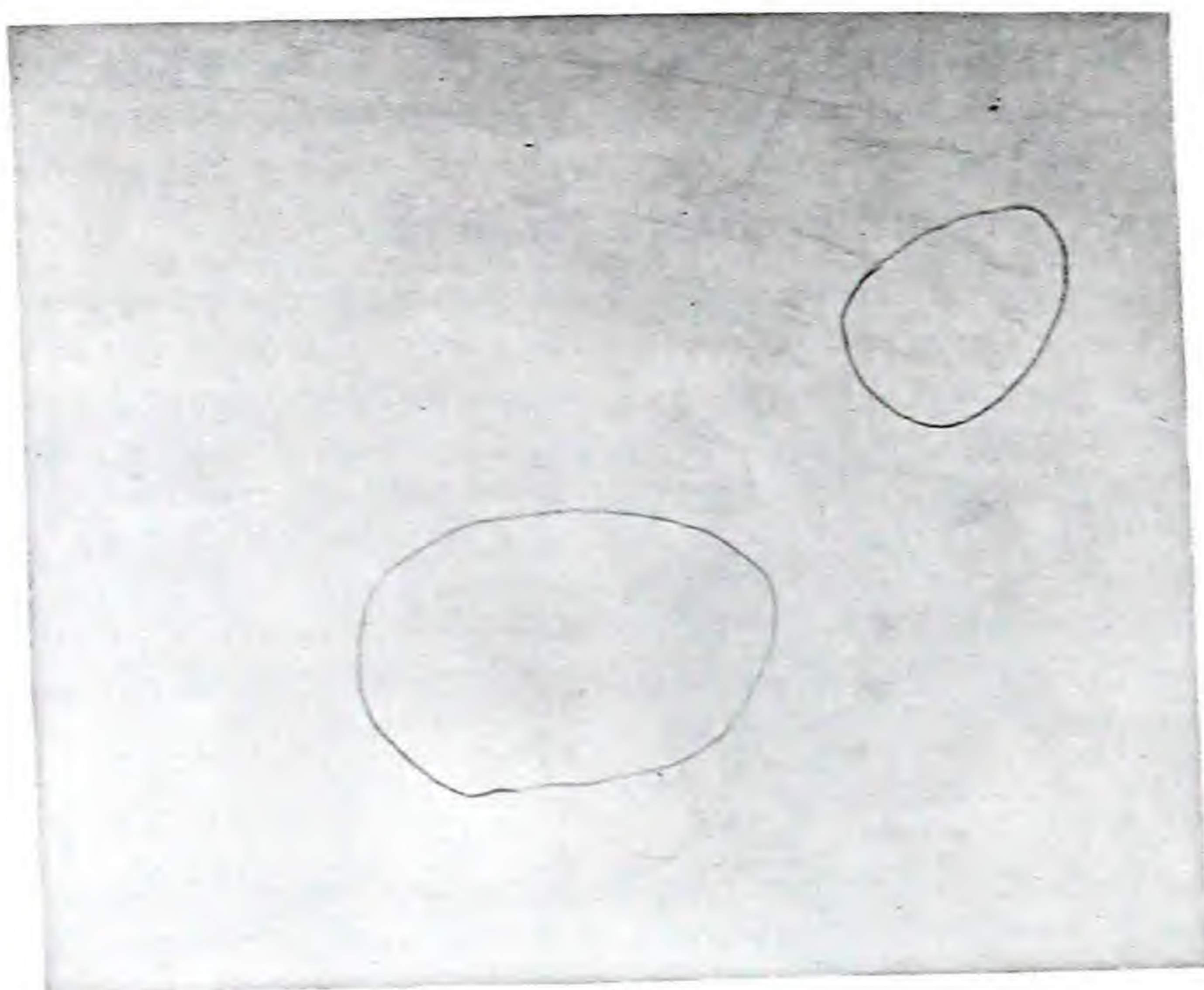
##### Gems

Differences in gems can be sometimes detected by their fluorescence. Sapphires, diamonds, and rubies differ in fluorescence depending upon the locality from which they originate. True and artificial pearls can be distinguished by the differences in transparency to ultraviolet light. If the image varies in density, the pearl is genuine; if the image is uniform in density, the pearl is artificial.

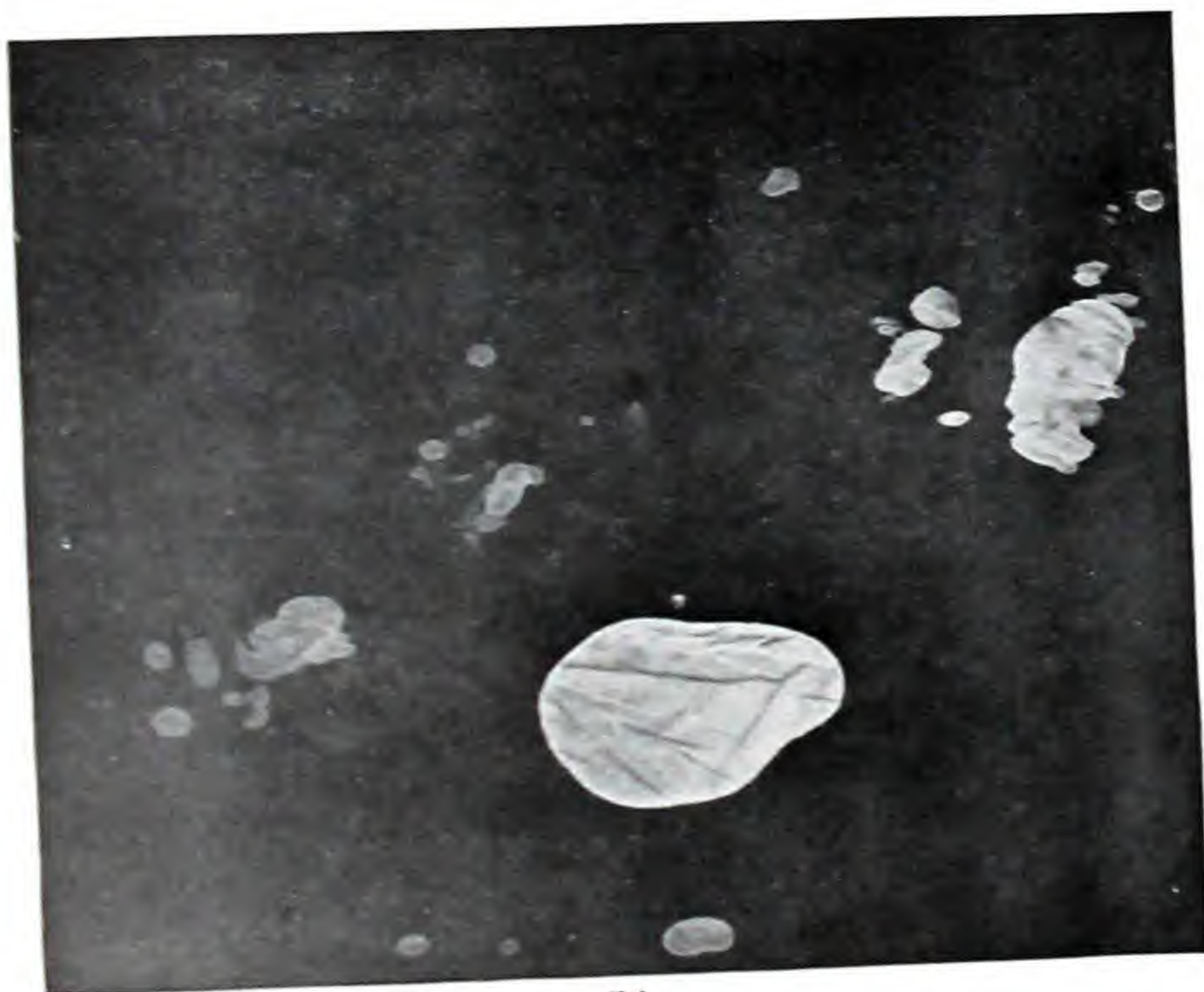
##### Teeth

False teeth are dark in ultraviolet light; natural teeth fluoresce white.





(a)



(b)

Fig. 157. Stains on a sheet revealed by means of a fluorescent examination: (a) a photograph in ordinary light; (b) under the ultraviolet lamp.



### **Fingernails, Polish, Cosmetics**

Fingernails fluoresce. Some polishes are fluorescent. Lipstick and rouge sometimes contain rhodamine B or other fluorescent dyes. Skin which has lost its pigment will fluoresce in those areas.

### **Secret Writings**

Some secret writing materials are intended to be invisible in ordinary light and visible in ultraviolet light. Other materials, such as urine, milk, sputum, etc. to which a prisoner may have access, although they are intended to become visible on the application of heat, will fluoresce under ultraviolet light (Chap. 36).

### **Altered Documents**

As a matter of routine, documents which are suspected of being altered should be submitted to an ultraviolet examination. Spots which fluoresce may have been treated with an ink eradicator. Differences in fluorescence may be due to an erasure. Lack of fluorescence where the material fluoresces uniformly may also be significant.

### **Altered Seals**

If it is suspected that a letter has been opened and resealed, a preliminary ultraviolet examination should be made. Glue fluoresces brightly. Gum arabic fluoresces, the intensity varying with different waxes and with the lapse of time since melting. In examining the suspected letter or parcel, attention should be given to differences in intensity and color of fluorescence, which are indicative of resealing.

### **Counterfeit Tickets and Coupons**

Forged tickets are usually made by a process differing from that used in producing the original. There may be a difference in sizing, tone of paper, or colored printing ink. This difference is sometimes clearly seen by the disparity in intensity of fluorescence. Parimutuel tickets, which are used at race tracks as evidence of an existing bet, are looked upon by counterfeiters as favorable subjects.

### **Laundry Marks**

It is the practice of some laundries to place on garments entrusted to them an invisible identifying mark. This mark, which is usually a serial number, fluoresces under ultraviolet light (Fig. 131). Common classes of cases in which laundry marks are of great value are those of abortion and abandonment of children. In abortion a towel or sheet is commonly used to wrap the child or foetus. This towel or sheet should always be examined for fluorescent laundry marks. A file of laundry marks should be maintained so that the owner of the towel or sheet may be traced through this laundry. In abandonment cases, a





(a)



(b)

Fig. 158. A fingerprint on a multicolored background developed with a fluorescent powder and photographed a in ordinary light; b in ultraviolet fluorescence.



diaper and receiving blanket are usually found on the child. Since abandonment is usually a result of poverty and since the poor are not given to sending baby garments to laundries, the prospect in these cases is not very hopeful. Nevertheless, the examination should always be made.

In other cases the perpetrator may leave some article at the scene and from the laundry marks contained thereon his identity may be established. For example, a handkerchief used to tie a victim's hands, or a shirt changed for a fresher one would be valuable evidence, and an ultraviolet examination will generally yield profitable results.

### **Fingerprints**

The matter which may be deposited by the finger after contact with a surface may contain traces of a fluorescent substance. Where it is undesirable to use any of the powdering or other techniques of fingerprint development, an ultraviolet examination should be made. Figure 158 is a photograph of a fluorescent fingerprint which was developed with fluorescent powder because of the confusing background.

### **Statues, Pottery, Ceramics**

Cases occur where the age of pottery or statuary is in question. Differences in fluorescence of pottery allegedly from the same source are indicative of difference in age. Repairs and retouching are also revealed in this manner. Old marble fluoresces differently from new marble. Alleged antiques should be suspected where these differences are evident.

### **Paintings**

Ultraviolet examinations are useful in questions of the authenticity of paintings attributed to old masters. Old varnish has a strong fluorescence. Hence, retouching, repairs or other alterations may become visible as dark areas in the fairly uniform fluorescence. Examples of paintings executed over a much older original have been detected by the difference in intensity and color of fluorescence.

## **INFRA-RED EXAMINATIONS**

### **5. THE INFRA-RED REGION**

The infra-red region of the electromagnetic spectrum includes the wave lengths from 7600 Å to  $4 \times 10^6$  Å. This includes the region which is now termed *microwaves*. The spectrum region of particular interest to the police scientist ranges from 7600 Å to 20,000 Å. Its importance lies in the fact that it includes the wave lengths which are invisible to the eye but which affect photographic plates. The appearance of an object under infra-red radiation may be quite different from its normal aspect. For example, two pieces of cloth of the same material may appear similar in ordinary photography. An infra-red photo-



raph, however, may reveal a distinct difference in tone. One piece of cloth may appear black and the other light in the photograph. Thus, although the eyes appeared the same in visible light, their infra-red radiations were quite different (Fig. 159). In the following applications this possibility of a difference

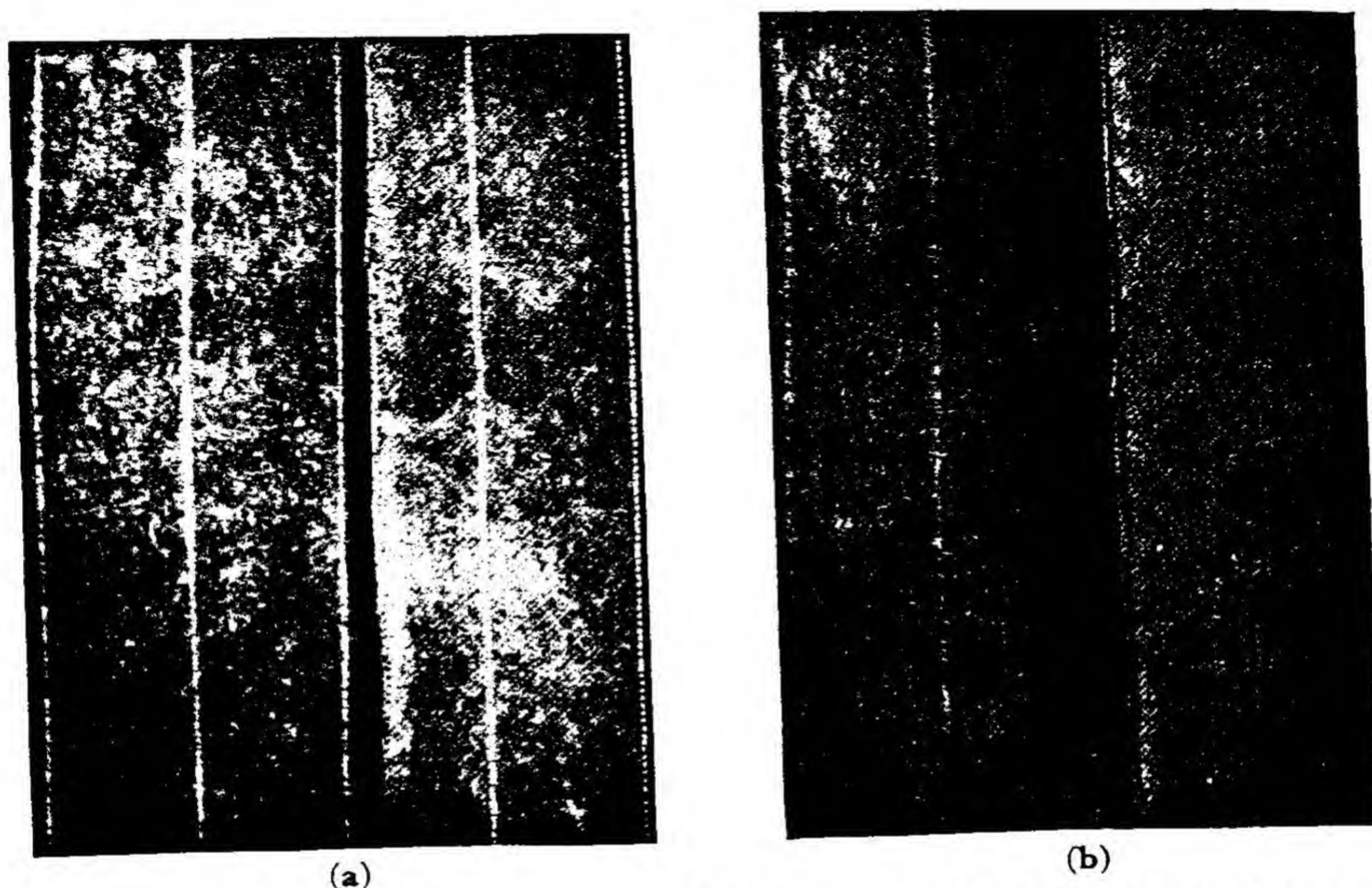


Fig. 159. Differentiating dyes by infra-red photography. The two cloth samples appear similar in ordinary light (a). In the infra-red (b) the difference is apparent.

of contrast in infra-red radiation is being tested in each case. (The terms *opaque* and *transparent* will be used below to indicate respectively whether an object does or does not reflect infra-red radiation.)

## 6. CLOTH, PAINTS, AND STAINS IN THE INFRA-RED

### Cloth<sup>1, 2, 3, 4, 5</sup>

In motor vehicle homicides a few fibers are sometimes found on the grill-work, headlamp, bumper, or tire of a suspected car. An infra-red photograph of the fibers found on the car and of a sample of the fibers of the victim's clothing should be made (in addition, of course, to the other tests for the comparison or analysis of fibers).

### Paints<sup>6</sup>

Although a comparison of paints should ordinarily be made by a spectrographic or color analysis, where the instruments are not available other methods must be used. An infra-red photograph may in such a case reveal valuable information. Most colors of paints photograph white in the infra-red. Scarlet, orange, yellow, vermilion red, crimson, and their variations will usually photo-



graph white. Paints which have colors of carbon black and iron blue will photograph as black. Hence, chinese blue, ivory black, and prussian blue will photograph black. Indigo, sky blue, and cobalt blue, however, will photograph white. Iron blue is sometimes found in certain greens and browns causing these to photograph as gray, depending on the relative quantity of iron blue present.

### Stains

It has previously been stated that ultraviolet light is the best means of examining a garment or other object for stains. This method, however, depends for its efficacy upon the fluorescence of the staining substance. Gunpowder stains, for example, do not fluoresce. Thus when it is suspected that this type of stain is present on dark clothing, its pattern may be clearly revealed if the dye of the suit is not too opaque to infra-red rays. The photograph will give the needed contrast to the gunpowder stain because the carbon and other decomposition products present are opaque to these rays. Figure 160 shows how useful detail invisible in ordinary light is made visible by infra-red photography.

No set rules can be given for stains in the infra-red. The relative opacity of the stain is a function of the infra-red region in which the photograph is made. The experiment must be made in each case. The value of such a photograph is not to be gainsaid, however, since the information thus revealed will reduce testing *for* stains to testing *of* stains.

## 7. DOCUMENTS AND THE INFRA-RED

### Inks <sup>7.5</sup>

A recurring problem in criminalistics is that of deciphering writing which has been obscured by superimposition of other writing. The writings cannot usually be chemically separated. If they are of the same color, filters will be of no avail. If, however, the upper ink is transparent to infra-red and the lower ink is opaque, it will be possible to render the under writing legible. Usually it is difficult to predict results.

The following writing inks are relatively opaque to the infra-red: Chinese or India inks, iron tannate inks, and chrome logwood inks. Colored inks (i.e., green, blue, red, or violet) containing synthetic aniline dyes or natural coloring



Fig. 160. Powder mark surrounding a bullet hole in a dark colored suit photographed with infra-red film.



natter, such as indigo, are transparent. In general, however, it is impossible to predict the behavior of inks in the infra-red region. Mitchell<sup>9</sup> states that the degree of transparency of different inks to infra-red rays depends upon the composition of inks as well as upon their physical properties. Further, he points out the fact that in certain inks the differential separation of the blue dye by the capillary action of the fibers of the paper is an important consideration. Since the type of ink under investigation is usually unknown, and physical properties in question are difficult to determine, the investigator should rely on experiment in each case.

### **Erasures** <sup>10, 11</sup>

In mechanical erasures the ink or pencil may not be completely removed; small invisible traces may remain behind. If these traces are present in sufficient quantity to form an outline of the writing, an infra-red photograph can render the writing visible since the carbon, graphite, and certain inks are opaque. Writing which has been apparently removed chemically should also be subjected to this treatment.

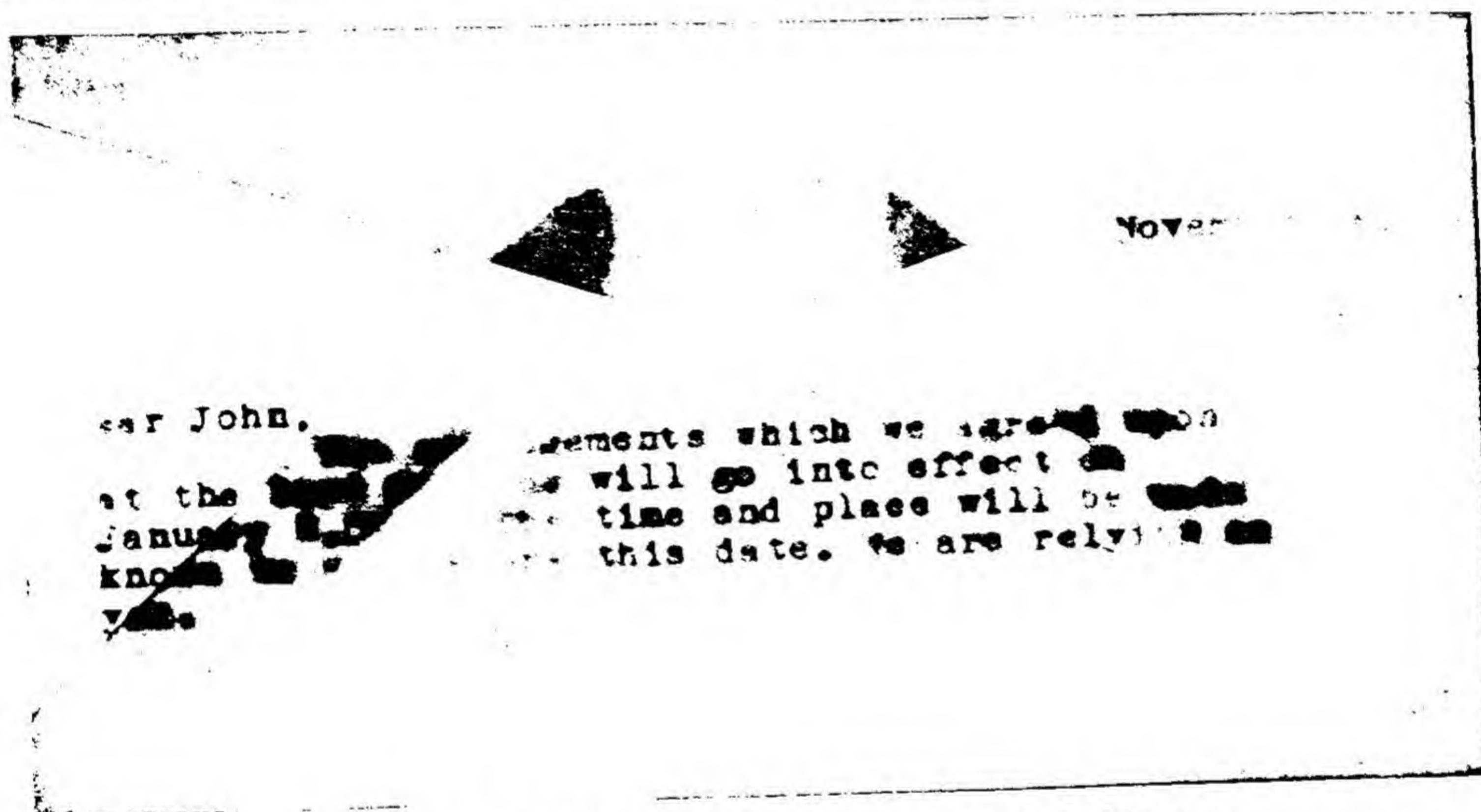


Fig. 161. An infra-red photograph of a sealed letter.

### **Burned Documents** <sup>12</sup>

Charred papers on which the writing has become invisible because of the burning may sometimes be made legible in an infra-red photograph. The success of the experiment depends upon the nature of the ink or pencil used, the degree of charring which the document has suffered, and the composition of the paper. This subject is treated in Chapter 37.

### **Secret Writing**

Certain kinds of secret writing are rendered visible by an infra-red photograph. Again, success by this method is generally unpredictable and the experi-



ment must be made as part of a thorough examination. Reference has been made to this procedure in Chapter 36.

### Unopened Letters

It is sometimes found necessary, during the course of an investigation, to discover the contents of a sealed envelope without opening it (Fig. 161). Infra-red photography is sometimes helpful here. The letter is placed on the glass in a printing frame. A sheet of infra-red film is placed over the letter and the back of the frame is closed. The frame is then exposed to an infra-red light source. The exposure will depend upon the thickness of the contents of the envelope.

### 8. SHADOW PHOTOGRAPHY<sup>13</sup>

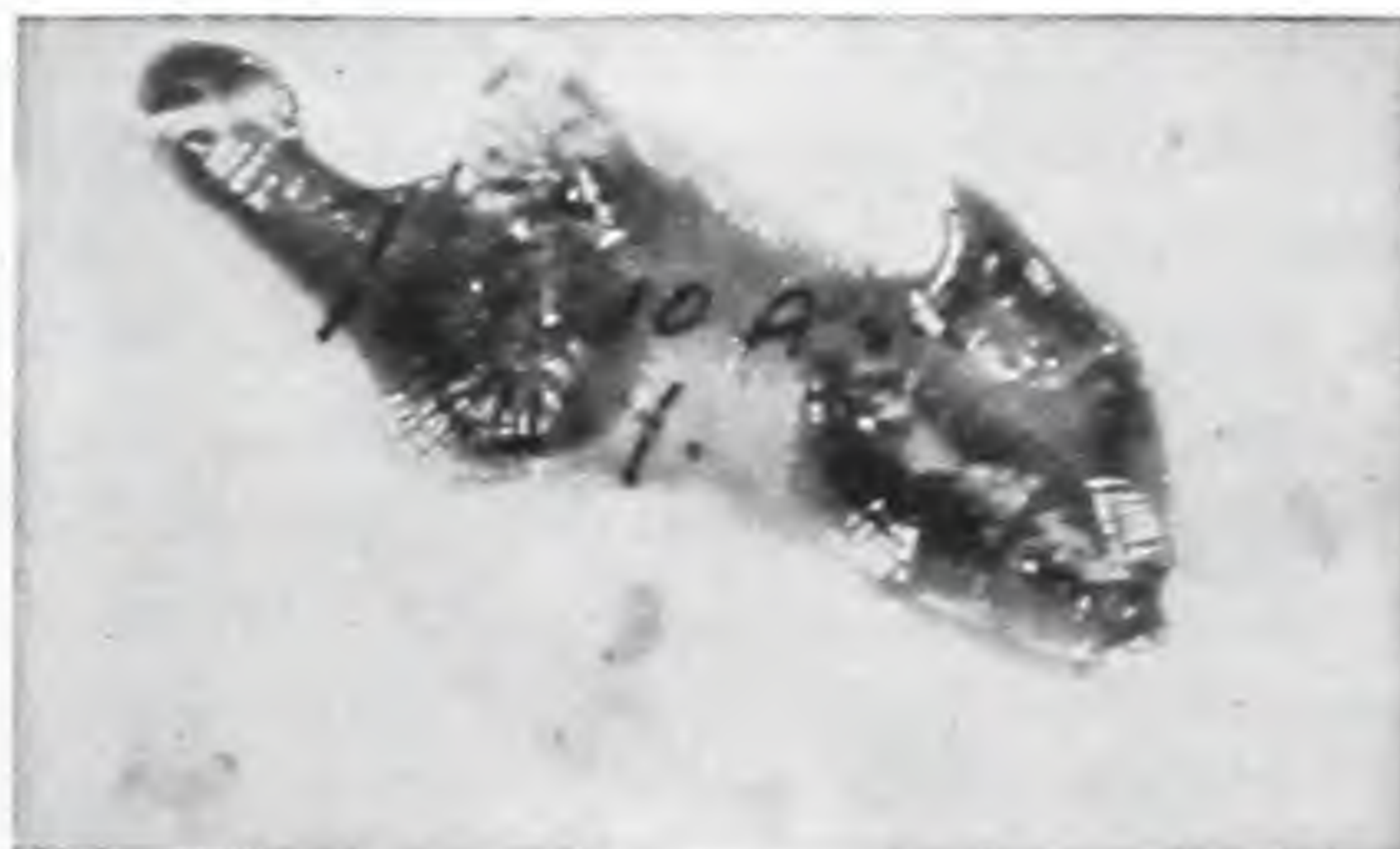
The technique described above for unopened letters is an application of the general method of shadow photography due to Plotnikov. This method of photography has been applied to the study of other objects such as biological specimens and metal foils. A notable application is the distinguishing of artificial from real pearls.<sup>14</sup> The larger nucleus of the artificial pearl produces an opaque area in the negative which is larger than that produced by the real pearl.

### 9. MISCELLANEOUS<sup>15, 16, 17, 18, 19, 20, 21, 22</sup>

The reader will have observed that the success of infra-red photography in criminalistics must be determined empirically in each case. The police scientist has been advised to experiment wherever he sees a possibility of success. At present we know that infra-red radiations emanate from all bodies which are not at absolute zero. The hope in an infra-red examination is that the difference in degree of reflectance from different parts of an object may be discovered photographically so as to yield profitable contrast. Thus, it is recommended



(a)



(b)



(c)

Fig. 162. Writing obscured by a blood stain: (a) normal appearance; (b) photographed by reflected infra-red; (c) photographed by transmitted infra-red.



that all specimens of obscured markings or writings should be submitted to the infra-red process as part of the routine physical examination. Illegible cancellations, worn inscriptions in shoes, altered records, cards, licenses, etc.; illegible markings on cloth, leather, or other substances; fraudulent paintings; and many other problems of deciphering which the investigator may meet should not be abandoned until an infra-red photograph has been made. Where moderate success is achieved the possibility of improvement by oblique lighting or other variation of the illumination should be considered.

## 10. INFRA-RED EXAMINATIONS WITHOUT PHOTOGRAPHY

Within the past decade the possibility of transforming the invisible infra-red image into a visible image by means of an electronic device such as an image converter consists of a means of forming an image on a surface, and an electron-optical image-forming device which projects the electron image on a fluorescent screen where it can be observed. The photosensitive surface will react not only to the infra-red radiation but to visible light as well. Certain surfaces such as caesium on oxidized aluminum are sensitive to radiation as long as 11,000 Å. The recent development of the Cathicon tube leads us to expect that the examination of objects under infra-red radiation by simply observing the transformed image on a fluorescent screen will become as much a matter of routine as fluorescent examinations in the ultraviolet region and x-ray fluoroscopy. The so-called *snooperscope* which was developed in World War II is a practical device through which objects can be observed by means of infra-red radiation.

## EXERCISES

1. Examine the following substances under ultraviolet light: camphor, aspirin, alpha naphthylamine, salicylic acid, uranyl nitrate, rhodamine B, a coal tar hydrocarbon such as chrysene or fluorene, seminal stains, urine, and blood. Notice the different intensities and colors of fluorescence.
2. Select a number of objects such as stamps, envelopes, paper with greasy fingerprints, teeth, glass, and observe the fluorescence.
3. Using milk and a pen write a message on a piece of paper. Examine under ultraviolet light. Repeat this exercise using urine as the sympathetic ink.
4. Select a series of inks of well-known brands and with each ink write on one line of the same piece of paper. Photograph in infra-red and note the relative opacity of each ink.
5. Select the most transparent and the most opaque of this series of inks and obscure a line of writing of the latter with lines of the former. Photograph to discern the lower writing.
6. Select an opaque ink from the series, write on a sheet of paper and burn the paper so as to achieve varying degrees of charring. With 35 mm infra-red film make a series of photographs in which the writing is legible.
7. Using five different inks (relatively opaque) and five different types of pencils, make a set of ten erasures on one sheet of paper. Write the same text in each case. Photograph by infra-red.



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# CHAPTER 22

## X-RAYS

### 1. INTRODUCTION

Many readers will be acquainted with the use of x-rays in medical and dental examinations, but the more recent applications to industrial problems and criminalistic work will probably be less familiar. As a matter of fact, so extensive has been the increased use of this method of physical inspection of materials that special films have been developed to meet the demand in this field for speed, lack of graininess, contrast, and other desirable photographic qualities. In this chapter, it is intended to indicate the possible application of these rays to the examination of clue materials and to other police investigations; in addition, the general principles that guide industrial radiographers in their work will be studied together with some modifications appropriate to the more unusual applications in police work.

### 2. APPLICATIONS TO CRIMINALISTICS <sup>1, 2</sup>

There are two distinct kinds of x-rays which are used in police investigations: *hard* x-rays, which have relatively great penetrative power; and *soft* x-rays, which border on the short ultraviolet and therefore possess less penetrative power. Indeed, it is this lack of penetrative power that makes the soft x-rays useful and of interest to the investigator in the police laboratory.

#### Uses of Hard or 50–140 Kilovolt X-rays <sup>3</sup>

The use of x-rays in the examination of suspicious packages for explosive devices and mechanisms in sabotage and other criminal cases is perhaps the best-known and most obvious application of x-rays in criminalistics. Another important use of hard x-rays is in the search of baggage, upholstery, walls, etc., for secreted contraband such as guns and other dangerous weapons (Fig. 163). In suspected sabotage cases where an unexplained failure of a metallic part occurs, an x-ray examination may be helpful in locating structural defects such as voids in the metal which might account for the failure and preclude the possibility of sabotage.

The fact that visually similar substances vary in their absorption of x-rays



provides many interesting uses for these rays. Dice, for example, are sometimes "loaded" by insertion of a small piece of metal beneath the spots. A radiograph



Fig. 163. Radiograph of a suitcase.

such as that of Fig. 164, will clearly reveal the presence of the metal. True and counterfeit coins can be readily distinguished, particularly when lead is used in the counterfeit since a radiograph will reveal the greater absorption by this metal. Similarly, it is possible to differentiate between soft and lead glass by means of x-rays because of the greater absorption of the latter.

A further use of x-rays is in the field of identification. Dead bodies which are unidentified can be x-rayed to reveal dental work and characteristic bone structures such as the sinuses. These radiographs can be later checked against medical records of

missing persons. X-ray methods have been used also for recording the fingerprints (Chap. 8) of partly decomposed bodies<sup>4</sup> (Fig. 165).

#### Uses of Soft or 4–25 Kilovolt X-Rays<sup>5,6</sup>

Although these x-rays have been used in quasi-police work to detect forgeries of paintings of old masters,<sup>7-12</sup> they have been employed principally in industry for the examination of its products, manufactured or natural. Some applications which indicate their value in the police laboratory are the following:

(a) *CLOTHS AND FABRICS*.<sup>13,14</sup> It is possible to compare two samples of cloth or fabric material by studying their respective weaves and detecting the presence or absence of weighting materials such as tin or lead. In fabrics with complex weaves it may be necessary to make a stereoscopic radiograph in order to unravel the intricacies of the design and to make a thorough comparison of other structural details.

(b) *PAPER*.<sup>15,16</sup> Papers may be compared for similarities or differences in filler impurities and in the fiber structure of the paper. Hand-made papers may be shown to differ from machine-made.

(c) *LEATHER*. It is possible to compare and distinguish between artificial and natural leather, and thereby, in certain cases, make comparisons of clue materials of this type.

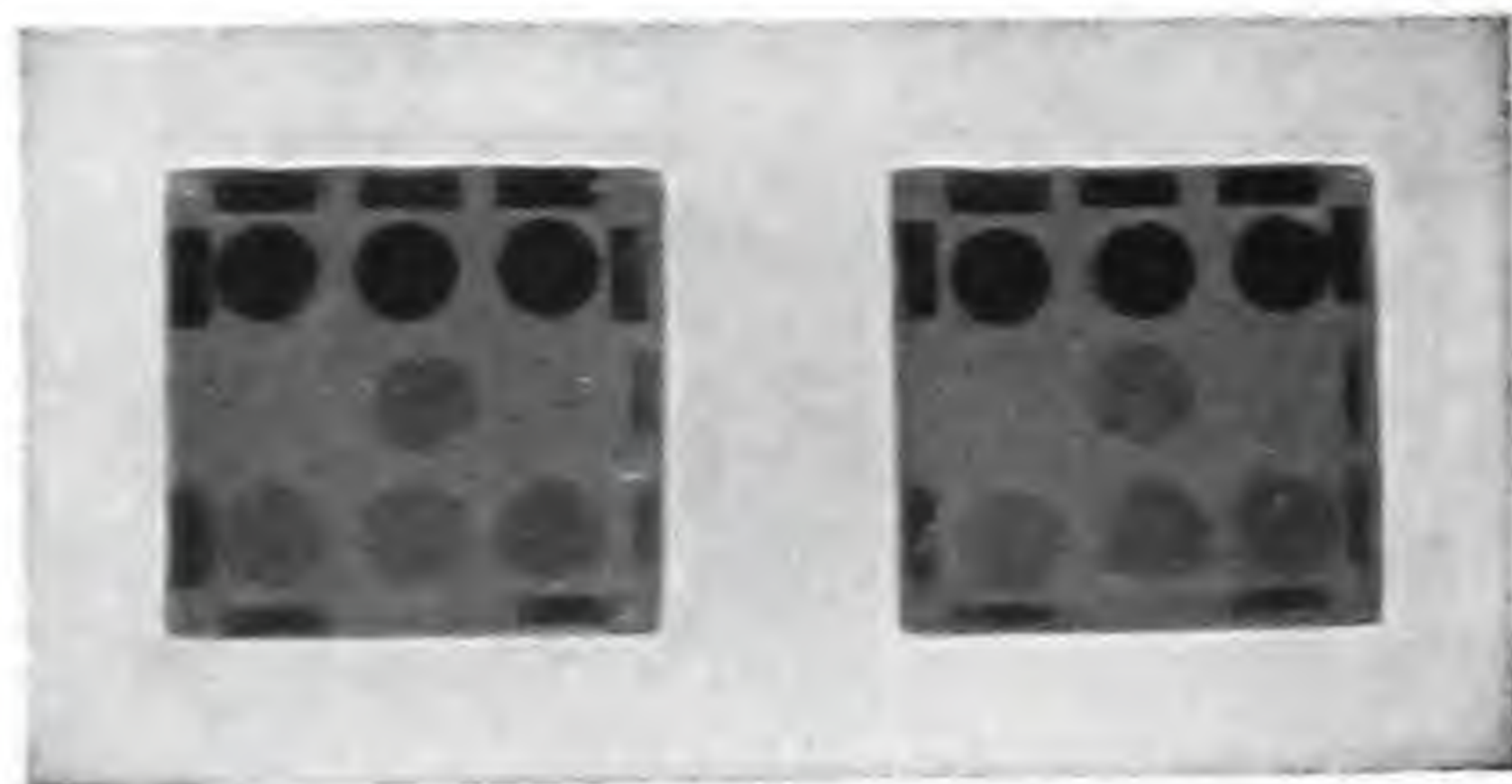


Fig. 164. Radiograph of filled dice.



(d) *JEWELRY*.<sup>17</sup> Imitation diamonds such as zircons and imitation pearls may be detected and distinguished from precious stones.

(e) *BIOLOGICAL SPECIMENS*.<sup>18, 19</sup> Additional information concerning the classification and structure of seeds, leaves of plants, insects, etc., may be gained from low-voltage radiographs. This information is of value in the comparison of clue materials of this nature with known samples obtained at the scene of the crime.

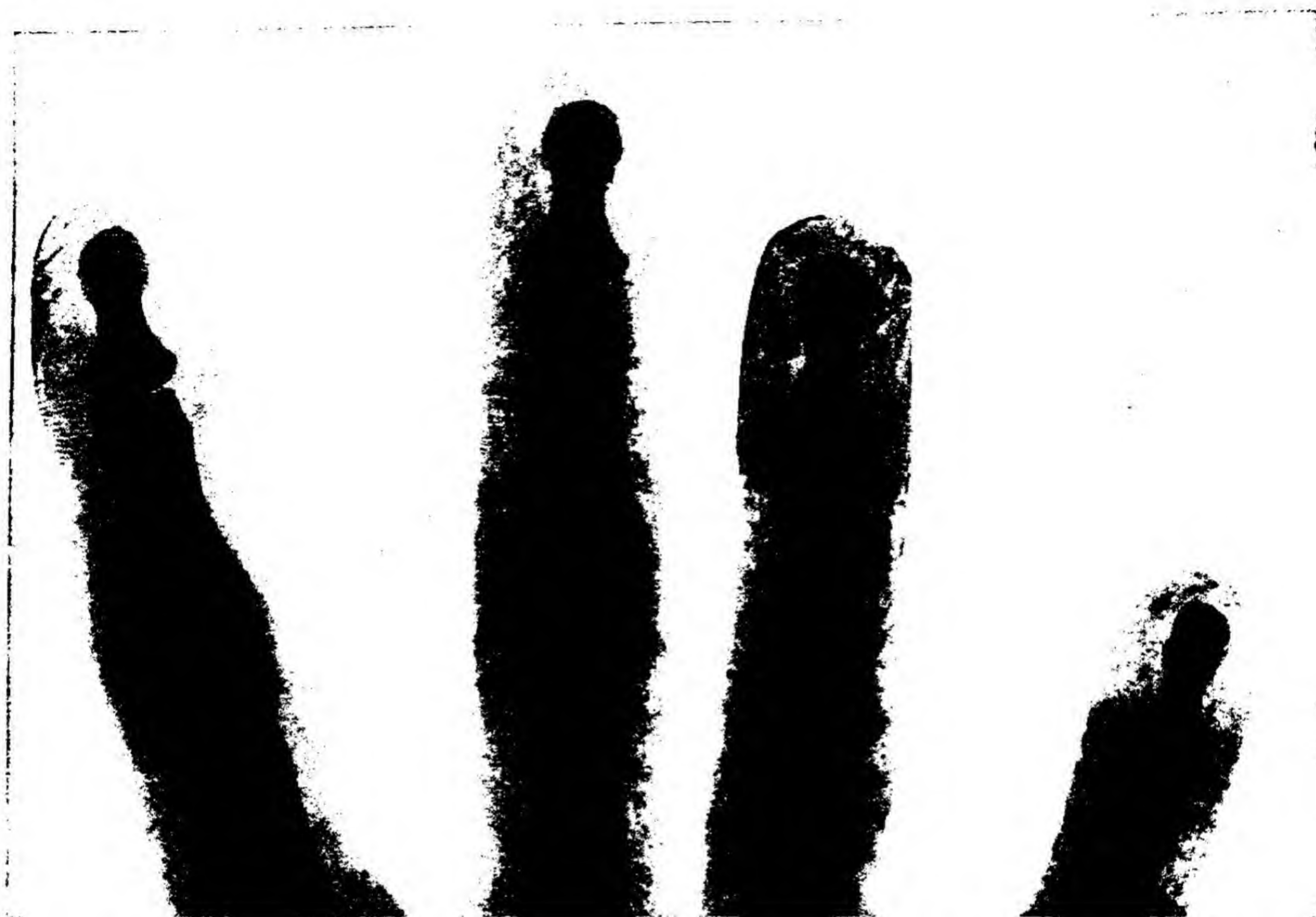


Fig. 165. Radiograph of a hand. The friction ridges of the index and ring fingers are visible.

(f) *GUNSHOT WOUNDS*. Another interesting application of these rays involves their use in the study of the distribution of lead fouling\* and (molten) lead particles about the entrance of a bullet hole in clothing (Fig. 166). This information, together with other data obtained by studying the conditions found at the entrance of a bullet hole, may enable the laboratory ballisticsian to estimate the muzzle-body distance at the time the gun was fired.

(g) *MISCELLANEOUS*. Occasionally, names, army or navy serial numbers, and other information of value for identification purposes are stenciled on garments in inconspicuous places such as the underfold of a collar or the inside of a pants pocket. When the paint used in the stenciling contains lead or other heavy metals, x-rays may be of value in deciphering the original lettering which may have been smeared or, through wearing, have become worn and illegible on the surface. Sometimes the paint may be partially transferred to an adjacent

\* Infra-red photography is also likely to be of value.



portion of the garment, if originally it was not permitted to dry properly before being used. In these cases low-voltage x-rays may be of assistance in the examination of the otherwise illegible and, perhaps, none too apparent lettering.

These long wave length x-rays may also be helpful in discovering the presence of secret writings on documents submitted for examination in this connection. In particular, invisible inks composed of heavy metallic inorganic salts such as barium chloride or lead nitrate are susceptible of detection by this means.

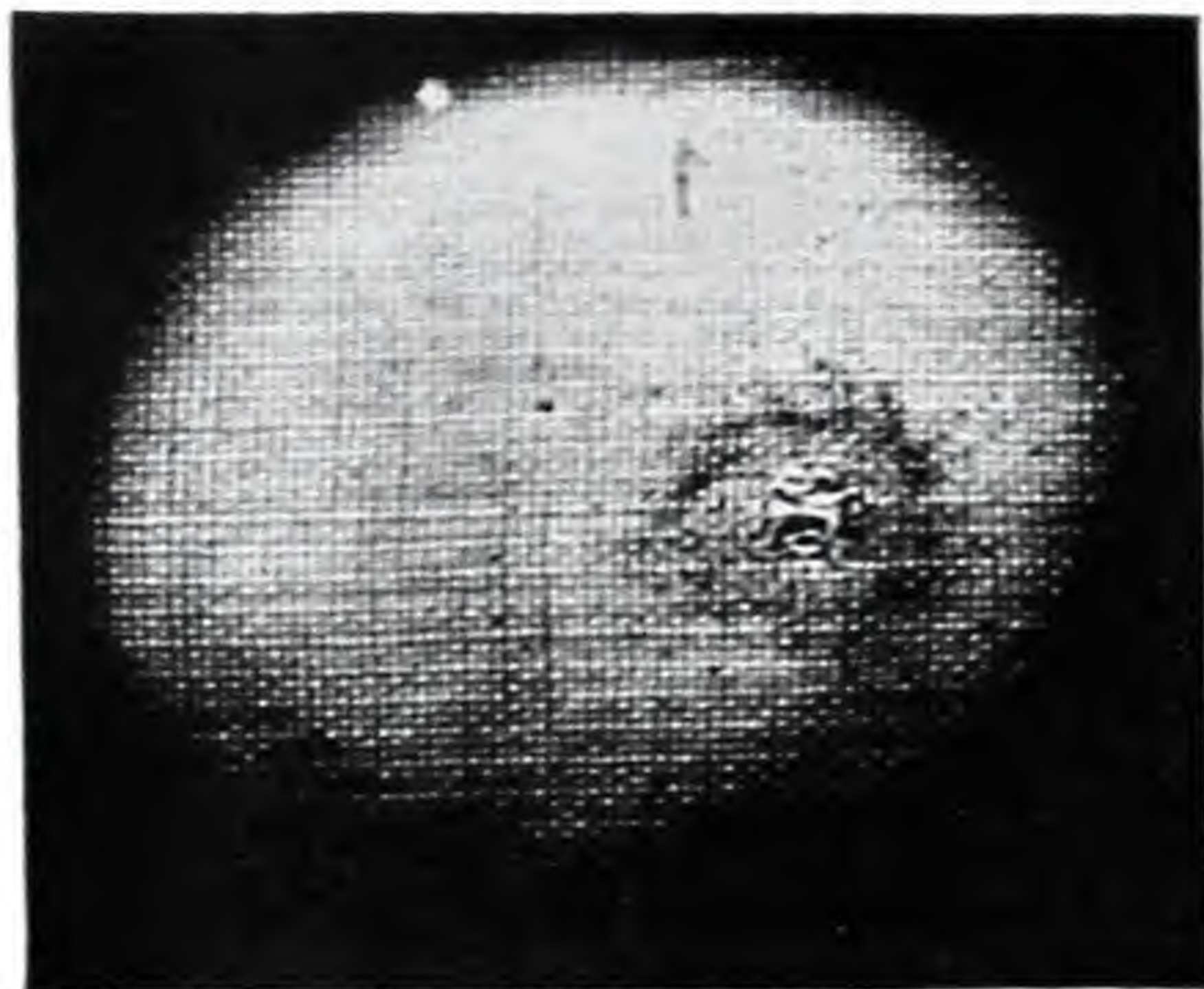


Fig. 166. Radiograph made with soft x-rays of a bullet hole in clothing, showing the distribution of the lead fouling around the bullet hole. The appearance of this hole to the unaided eye and process film is shown in Fig. 108. Technical data: 15 Kv, 10 ma, 8 in. distance,  $2\frac{1}{2}$  second exposure, No-Screen film, iron radiation. (Courtesy, North American Philips Co., Inc.)

### 3. DEFINITIONS

For the purposes of this chapter that portion of the spectrum which includes those wave lengths lying between 0.05 and 1000 Ångström units will be referred to as the *x-ray region* (see front endpaper). Contrary to the usual method of designation for electromagnetic energy, the practice in the x-ray field is to use the kilovoltage of the tube as an indication of the wave length region.

The advantage possessed by the short wave length radiations over the longer wave length light rays lies in the fact that materials opaque to light

are transparent to x-rays. This property of high-frequency radiations makes them valuable in the examination of the internal differences in construction and composition of many objects. For example, packages, cloths, wood, leather, etc., may be examined by passing x-rays through them; whereas, with ordinary light rays, one is able only to photograph the object without revealing anything about the conditions underneath the outer surface.

### Radiography and Fluoroscopy

By a *radiograph* is meant the shadow image produced in a photographic emulsion by x-rays which have been passed through an object. A closely related term which will also be used is *fluoroscopy*. The difference between radiography and fluoroscopy is in the manner in which the shadow image is detected. In fluoroscopy the x-rays instead of impinging upon a photographic emulsion are directed against a special screen (composed of calcium tungstate or similar substance) which has the property of converting the invisible wave lengths of x-rays to wave lengths of the visible region. In this manner the contrast that exists in the shadow image, owing to the relative ease with which the x-rays are able to penetrate various parts of the object, may be observed with the naked eye. When this image is permanently recorded on photographic emulsion it is referred to as a



radiograph (or radiogram). A satisfactory radiograph consists of a sharply defined image of sufficient detail to reveal the internal structural differences that exist in the object.

#### 4. X-RAY SOURCES

The usual source of x-rays is the Coolidge tube, the main features of which are illustrated in Fig. 167. The cathode, C, or negative pole is a tungsten filament which is heated by the indicated external low-voltage source. The filament, when heated to incandescence, is capable of emitting electrons which are drawn to the anode, A, by the impressed potential. The greater the energy supplied to the filament (by causing it to be heated to higher temperatures), the greater is the emission of electrons. This flow of electrons is referred to as *tube current* and is measured in milliamperes. The electrons are usually focused to hit a particular area of the anode known as the *focal spot*. The anode or positive pole is also called the *target*, and is usually made of a heavy metallic element of high atomic number and high melting point, such as tungsten or molybdenum. In the tubes used for low-voltage x-rays, lower atomic number elements such as titanium, chromium, iron, and copper are used as target materials. When the electrons from the cathode strike the target, x-rays are generated. A large amount of heat is also generated in the target by the electron bombardment so that the temperature of the tube must be closely watched. A thermometer is usually provided, which must be watched by the operator if he is to avoid burning out the tube, unless it is water cooled as may be the case in certain nonportable low-voltage equipment. It is for this reason that the focal spot or the actual area of the target undergoing electron bombardment is made larger than would be desirable from the standpoint of its influence on the sharpness of the radiograph.

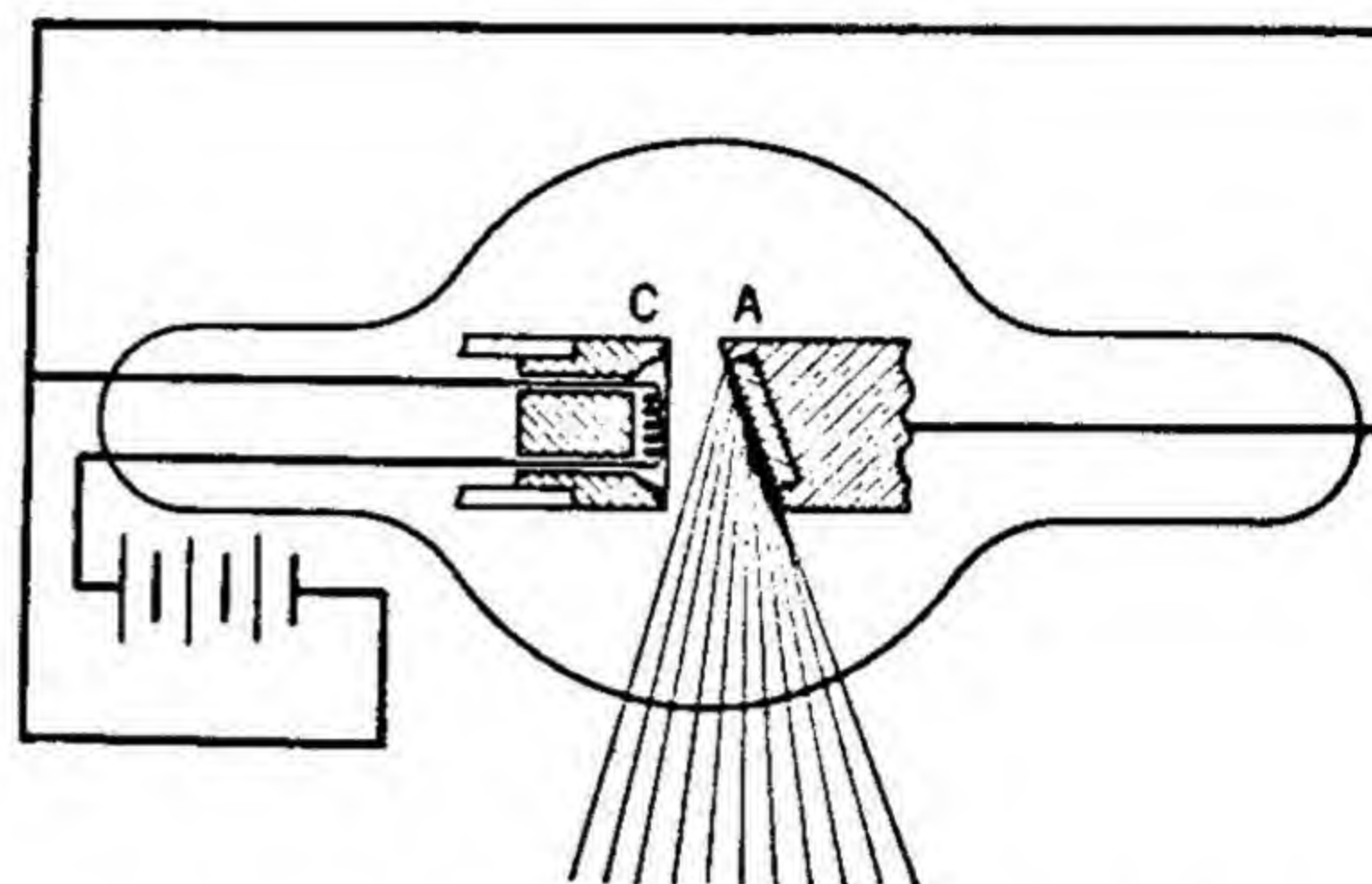


Fig. 167. Schematic diagram of an x-ray tube.

#### 5. THE X-RAY TUBE

##### Tube Current

The flow of electrons or tube current is measured in milliamperes and is controlled by the temperature of the heated filament. The greater the tube current, the greater the production of x-rays by the tube, so that the intensity or quantity of x-rays emitted in unit time is proportional to the tube current, other conditions being equal. The exposure time required to produce a radiograph is inversely proportional to the tube current, other conditions remaining the same.

##### Impressed Potential

The potentials impressed in x-ray tubes employed in criminalistic procedures range in the order of 4–25 kv for soft x-rays to 50–140 kv for the hard x-rays.



used in the examination of suspicious packages. By the adjustment of the potential supplied to the tube it is possible to control wave-length range of the x-rays produced. Wave length and potential are related by the following expression:

$$V \times \lambda = 12,345$$

where  $V$ , the potential, is expressed in volts and  $\lambda$  is the shortest wave length in Ångström units. The higher the impressed potential, the shorter the wave length and the greater the intensity of the x-rays emitted. The penetrative power of the x-rays is related to wave length: the shorter the wave length, the greater the ability to penetrate a given object. Thus, the higher the potential supplied to the x-ray tube, the greater the penetrative power of the emitted rays and the smaller the exposure time, other conditions being equal. This may be better

illustrated if it is considered that a tube operating at 140 kv produces all the rays operating at 50 kv, but the former also sends some of shorter wave length. Thus, the tube operated at the higher potential sends more rays per unit area and some of which are of shorter wave length and greater penetrative power.

### Focal Spot

The actual area of the target which undergoes electron bombardment is called the *focal spot*. In order to obtain the best possible definition or sharpness

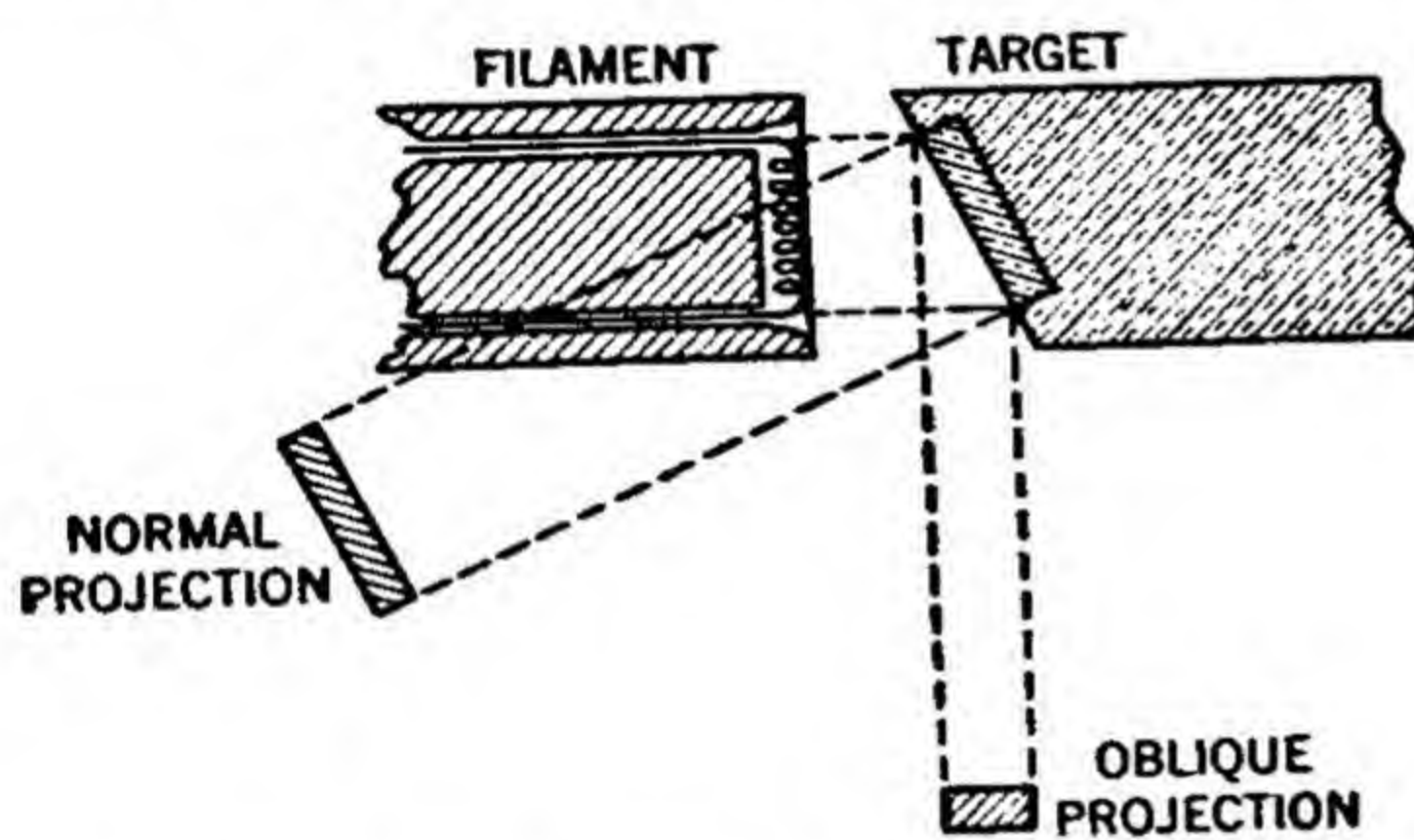


Fig. 168. "Line focus" or oblique projection of the focal spot.

of the radiographic image, the size of the focal spot should be as small as possible (Fig. 170a and b). However, the difficulty of dissipating the heat formed at the target as a result of electron bombardment usually requires that the size of the focal spot be increased to an area greater than would otherwise be desirable from the standpoint of definition. Tubes used for intense beams of x-rays also require a larger focal spot for the same

reason. A method which enables the manufacturer to achieve both effects (large actual area for the dissipation of heat and small effective area for the purpose of definition) consists of using an oblique projection of the actual area as the effective source of the x-rays instead of the normal projection of the focal spot (Fig. 168). This is the principle of *line focus*. Figuratively, as we shall see, it allows us to have our cake and eat it at the same time.

## 6. INTENSIFYING SCREENS AND PHOTOGRAPHIC EMULSIONS

In order to produce a radiographic image or x-ray picture, the x-rays must affect the film emulsion. The penetrative power of x-rays is such, however, that we should expect them to pass through the film leaving the emulsion unaffected. The facts of the matter are that less than 1 per cent of the incident radiation



actually affects the emulsion to form the latent image; the remaining 99 per cent passes through the film. This latter radiation which does not affect the emulsion in its initial passage may fog the film by reflection from surfaces beneath the film holder. This is similar to the well-known phenomenon of halation in photography.

An intensifying screen is a means that enables more of the radiant energy to be utilized with a consequent decrease in exposure time. The decrease in exposure time achieved by the use of a screen is such that about  $\frac{1}{16}$  to  $\frac{1}{4}$  of the exposure time necessary in the absence of a screen suffices.

### Calcium Tungstate Screens

Calcium tungstate is a chemical which fluoresces under the influence of x-rays. Thus, the impinging x-rays are converted by the tungstate screen to ordinary wave lengths; these in turn contribute to the formation of the latent image in the film and in so doing decrease the exposure time.

Because the normal exposure time is considerably diminished when tungstate screens are employed, they are known as *fast* screens. However, they increase the graininess of the image and thereby diminish the sharpness and definition which would otherwise be possible. In the use of 50-140 kv x-rays in police problems, sharpness and definition are of much less importance than the question of penetration and exposure time, since the interest is in an over-all, gross inspection of the interior of enclosed packages, suitcases, etc., rather than a detailed, critical examination of some small portion of the object as is usual in industrial work.

Tungstate screens are somewhat expensive, and certain disadvantages inherent in their construction such as fragility and susceptibility to spots and scratches which affect the radiographic image have decreased their relative value to industrial radiographers since the advent of million-volt x-rays and gamma rays. However, they still retain usefulness in connection with radiographic problems in criminalistics.

### Lead-Foil Screens

Mention only shall be made here of this type intensifying screen since it is not especially helpful in police work because the exposure time is at best reduced to only one-half the normal time.

### Combination of Film and Intensifying Screens

Film holders which have intensifying screens incorporated in their construction are known as *cassettes*. In x-ray films the emulsion is placed on both sides of the celluloid base so that two screens are mounted in the cassette in a way such that the fluorescent surfaces are in contact with each sensitized side of the film.

We have seen in Chapter 13 that in ordinary photography the latitude of the film serves two purposes: (a) to cover a wide tonal range; (b) to permit



considerable error in estimating exposure time. This latter aspect of latitude is of great importance in police radiography where the objects x-rayed vary so in character that it is difficult to estimate the exposure time. A simple way of obtaining greater latitude has been devised for radiography.

In this method two films, *A* and *B* in Fig. 169, are used. These films differ in their emulsion speeds. The two films are placed in the cassette with a third

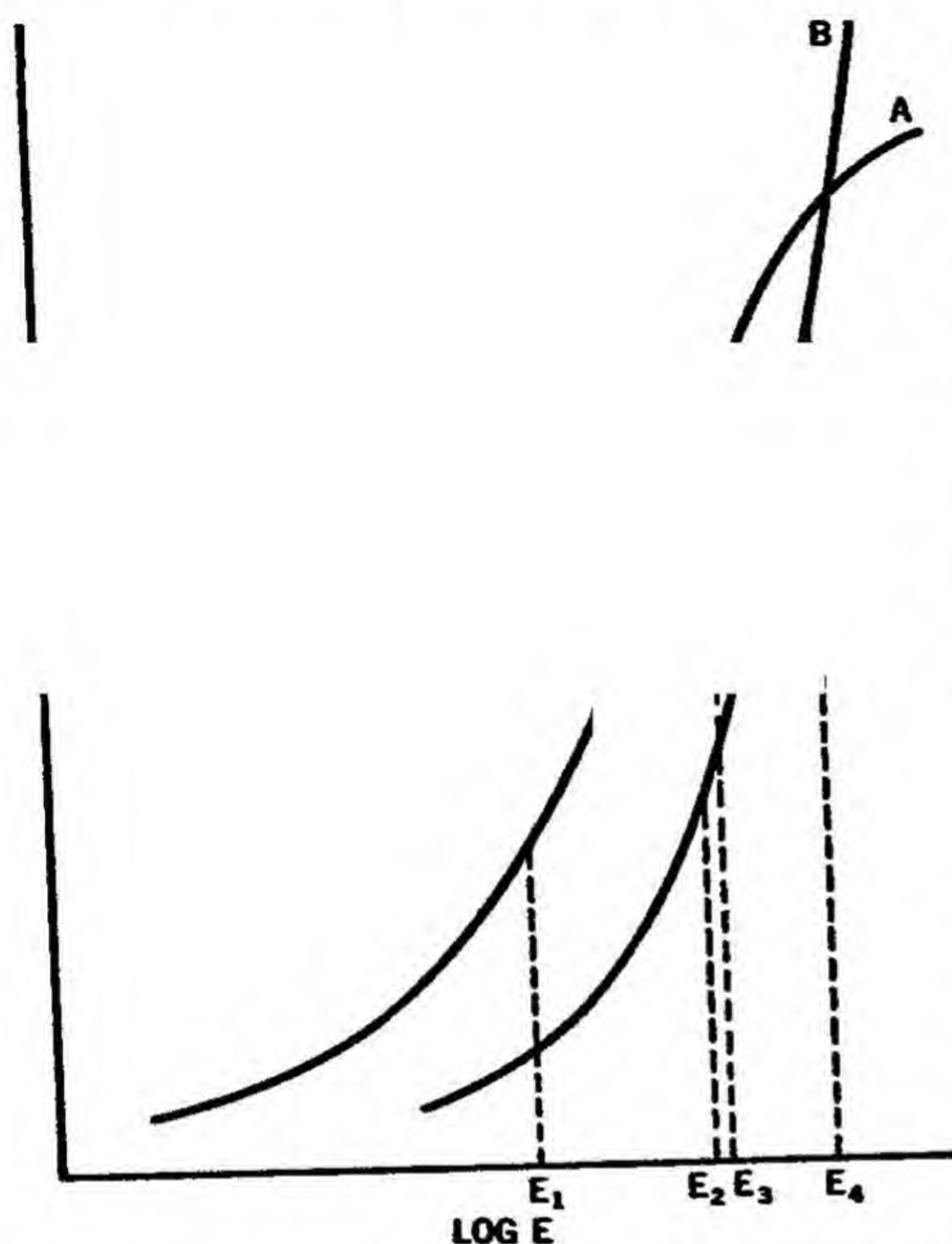


Fig. 169. Increasing latitude by using two films.

intensifying screen between them, if one is available for this purpose. The usual procedure is followed thereafter.

Referring to Fig. 169, we see that the latitude of film *A* is  $E_3 - E_1$  and that of *B* is  $E_4 - E_2$ . By the use of the two films together, the effective latitude is  $E_4 - E_1$ ; hence much greater error in exposure time is permissible. In addition, the other condition of latitude is fulfilled; namely, total range extended because exposures with respect to *A*, may be satisfactory for *B*. The two negatives studied in conjunction will then give a more complete picture. A comparison of the latitude in exposure for curve *A* (acceptable exposures range between  $E_1$  and  $E_3$ ) with that of curve *B* (exposure range being  $E_2$  to  $E_4$ ) reveals that if both films *A* and *B* are simultaneously used, the exposure may range between  $E_1$  and  $E_4$  and still produce a satisfactory radiograph. In

other words, this arrangement is the same as though a film with exposure range or latitude of  $E_1$  to  $E_4$  was employed.

### Photographic Emulsions

Although x-rays, like ordinary light rays, affect the sensitive emulsions of ordinary photographic films, it is desirable to have specially prepared emulsions available to take advantage of the distinctive properties of x-rays. Since the increased application of these rays to routine industrial inspections, there have been made available several types of film especially designed to meet the requirements of those working in this field.<sup>20</sup>

### Films for Use with 50–140 Kilovolt Apparatus

In general, one of the most satisfactory films, because of its latitude, is Eastman Kodak type F when used in conjunction with calcium tungstate intensifying screens. The method described above, that obtains increased latitude through the use of two emulsions of different speeds, requires that a slow film



such as type M and a fast film such as type K be simultaneously exposed in the same cassette with a tungstate screen sandwiched between them. Ordinary film of great latitude such as a portrait pan may be profitably used in many instances as the second film.

### **Films for Use with 4–25 Kilovolt Apparatus**

In addition to regular x-ray film, fine-grain emulsions are also used because in some cases it is necessary to enlarge the radiograph in order to study the detail in the image. The Eastman Kodak photographic materials available for this work are: No-Screen x-ray film, Industrial x-ray film, type M, Fine Grain Ciné Positive film, High Resolution plates 548–0.

No-Screen film and type M film will most frequently be satisfactory for the ordinary work involving the use of soft x-rays in the police laboratory. Dental film may be used for small biological specimens, with subsequent enlargements of 10 to 20 diameters possible without grain. Fine Grain Ciné Positive film also allows enlargements up to 20 diameters, while the High Resolution plates permit enlargements up to 100 diameters.

## **7. INTENSITY OF IMAGE**

The factors which influence the intensity of the radiographic image are listed below together with the variable controls which the radiographer may use to influence the results obtained.

### **Tube Current**

The greater the tube current the greater the intensity of the image obtained, other conditions being equal. By controlling the temperature of the filament in the tube the operator may influence the intensity of the image; the lower the filament temperature the lower is the intensity of the image, because the tube is emitting fewer x-rays.

### **Tube-Film Distance**

X-rays, like ordinary light rays, obey the inverse square law. This, however, is not strictly true for very low-kilovoltage x-rays since absorption by the air is no longer negligible. If the intensity of the image is  $I$  for a tube-film distance of  $D$ , then the intensity of any image produced at a tube-film distance of  $2D$  is  $\frac{1}{4}$  of the former, that is  $I/4$ . Thus the image intensity may be controlled by manipulation of the tube-film distance. In addition, this factor also affects the sharpness and definition of the image, the greater the tube-film distance the better the definition and sharpness in the image. In the 50–140 kv field the important considerations are those of penetration and exposure time, and not definition, so that the tube-film distance employed should be chosen on the former basis. In the 4–25 kv field, sharpness and definition in the image are of critical importance so that the greatest possible tube-film distance should be chosen consistent with a reasonable exposure time.



### Nature and Thickness of Material

The penetration of x-rays is dependent upon the nature and thickness of the material. Substances of high density and those possessing elements of high atomic number in their composition are more difficult of passage for x-rays. On passing through a substance the intensity of the x-rays falls off exponentially with the depth traversed, provided the beam is monochromatic (which ordinarily is not the case). Obviously the radiographer has no control over the nature or thickness of the samples which he is called upon to radiograph; he must rely on past experience and trial experiments in adapting his methods to each new problem.

Industrial routine examinations of the same type samples permit a *technic chart* to be made which provides data for estimating the exposure required for a police work, however, the kind of samples and the kind of experience of a theoretical and practical radiographer are the best conditions for making a suitable radiograph. This topic will be further developed later in

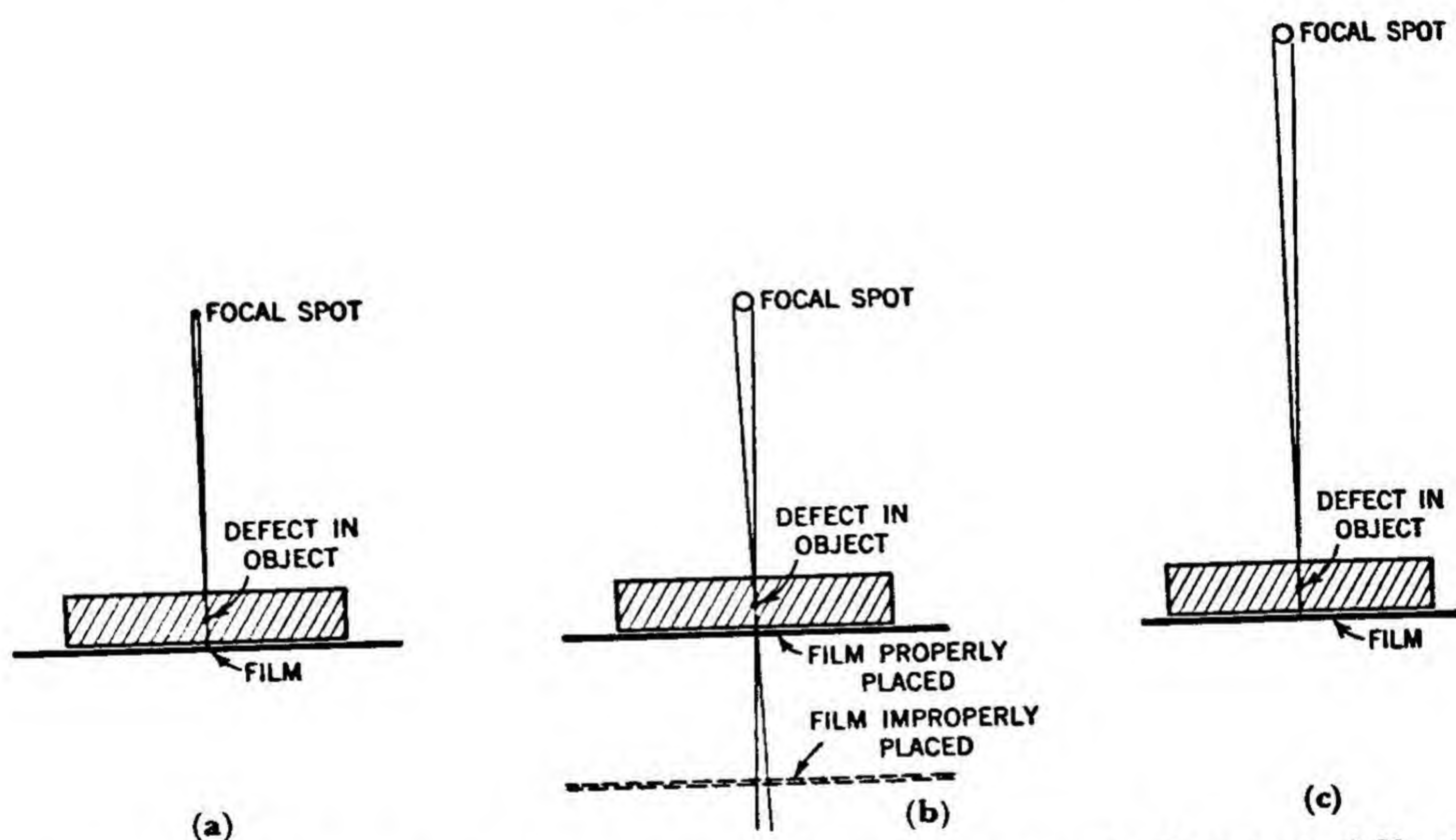


Fig. 170. Relation of size of focal spot, tube-object distance and placement of film to definition.

## 8. FOCUS AND DEFINITION OF THE IMAGE

The human eye requires less contrast to detect differences in detail when the image is sharp than when the image is fuzzy or lacks sharpness. For this reason it is advisable to have the radiograph as sharp and clean-cut as possible.

### The Size of the Focal Spot

The smaller the focal spot, the better the definition obtained in the radiograph (Fig. 170a and b). The principle of line focus enables the tube to meet



the requirements of heat dissipation and small focal spot (Fig. 168), so that the x-ray tube, by clever design, has been made efficient without greatly sacrificing one consideration for another.

### **The Distance from Tube to Object; Object to Film**

The greater the tube-to-object distance, the better the definition (Fig. 170b and c). The smaller the object-to-film distance, the greater the definition (Fig. 170b).

It must be remembered that the tube-object distance, in addition to affecting definition, also affects, according to the inverse square law, the exposure time. Since the requirements of good definition and reasonable exposure time are mutually opposed, it becomes necessary as the tube-object distance is varied to slight one arbitrarily in favor of the other. In the use of 50-140 kv apparatus in police work the exposure time consideration usually is of paramount importance, so that the distance is first selected on the basis of exposure and then, if any variation is permitted, consideration is given to the distance requirement for good definition. In the use of 4-25 kv apparatus the converse is true, so that the first consideration is given to definition requirements subject to the condition that a reasonable exposure time is possible at the distance chosen.

### **Intensifying Screen-Film Combination**

Fine-grain films are, of course, the best for obtaining definition but they usually possess slow emulsion speeds and require a longer exposure time. Therefore in the 50-140 kv field, slow films are not employed because of the exposure requirement. On the other hand in the 4-25 kv field it is especially necessary to use fine-grain film because the radiographs must frequently be enlarged.

The fast tungstate intensifying screens cause the image to be grainy and therefore less sharp, so that industrial radiographers prefer to use lead-foil screens instead. However, the exposure consideration requires the use of the tungstate screen in the 50-140 kv field in police work.

The decreased exposure required when a screen is used permits the tube-object distance to be increased so that a reduction in the exposure to  $\frac{1}{25}$  of normal permits an increase up to six-fold in the tube-object distance before the effective exposure time again is normal. Obviously the combination of fast film and fast screen, both of which introduce grain into the image imposes a limitation on an increased tube-object distance as a means of obtaining better definition. It has been found that for the average commercial tube the area of the focal spot is such that a ratio of 25 to 1 in the distances of tube to object and object to film is the maximum for producing the sharpest possible radiograph when fast film and tungstate screens are employed. To increase further the tube-object distance (keeping the object-film distance constant) will not result in better definition but will only increase the exposure time.

In the 4-25 kv field intensifying screens are not used, so that the above discussion is not applicable in this case.



By way of summary it may be said that the sharpness of a radiograph can be increased by using a tube of smaller focal spot, by moving the tube farther away from the object, and by moving the object closer to the film (see Fig. 170).

## 9. CONTRAST IN THE RADIOGRAPH

Contrast in the radiograph is equally as important as contrast in the ordinary photograph. In a low-contrast radiograph it may be very difficult to distinguish important detail because of the inability to discern gradations of tone. The factors which control contrast in photography will have the same influence on the radiograph, viz., subject contrast, film, and development. In addition, contrast in a radiograph may be influenced by the amount of scattered radiation. The factors will now be discussed in detail.

Scattered radiation comes from the target, the tube itself, and from the object being radiographed. When these rays are scattered in all directions, the greatest source of scattered radiation is the object itself, which generally is the largest source of scattered radiation, or by the material cassette, floor and surroundings, the result is undesirable. The reason for this is that as these non-image-forming radiations pass through the film the effect is the same as though partly fogged film were used, and the image contrast is decreased. Industrial radiographers have devised many methods of coping with this problem, such as using limiting diaphragms for the primary rays, shielding the object and film with lead sheets or masking them with lead shot or barium clay, Potter-Bucky diaphragms, etc. Cassettes are usually fitted with lead sheeting to eliminate back scattering. This precaution is sufficient for the purposes of the usual 50-140 kv examinations, and the effect upon contrast is not very important to the police radiographer. A direct relationship exists between the thickness of the material and the amount of scattered radiation, but again this is no problem in the 4-25 kv field since the specimens under examination are usually thin sections.

### Tube Voltage

It is easy to demonstrate experimentally that a high tube voltage reduces image contrast but at the same time results in greater film latitude; whereas a lower tube voltage results in increased image contrast, other conditions being equal. Thus, in the 50-140 kv field, where a wide film latitude is desirable in order to keep both thick and thin portions of the object on the straight line portion of the characteristic curve (Chap. 13) it is advisable to use the highest tube potential possible in making the radiograph. In the 4-25 kv field, where the purpose is to obtain the greatest detail possible, the lowest potential that will cause the object to be penetrated and which does not require too long an exposure should be chosen.

It should be expressly mentioned that in the preliminary fluoroscopic examination usually conducted when 50-140 kv x-rays are being used, the lowest



possible potential which will cause penetration should be used in order to minimize the danger to personnel, particularly when they are engaged in field work and have a large number of packages to examine.

#### 10. PROTECTION FROM X-RAY EQUIPMENT AND X-RAYS

The usual industrial x-ray apparatus is designed so that the operator is unable to come into accidental contact with the high-voltage parts of the equipment, but he should, nevertheless, be mindful at all times of the danger which exists when this equipment is being used.

Exposure to x-rays may damage the body tissues if continued for short periods over a long time or during one long period. The primary rays from the tube are most hazardous, but the secondary and scattered radiations also have their effect in time, so that the radiographer should observe all precautions such as wearing lead-lined gloves, lead aprons, and so forth. A more extensive treatise on this subject may be obtained from the Superintendent of Documents, Washington, D. C., in a booklet entitled "X-Ray Protection," HB20, National Bureau of Standards Handbook issued in July, 1936.

#### 11. DATA FOR THE PRACTICAL USE OF X-RAYS IN POLICE INVESTIGATIONS

It would be impossible to provide specific data for all types of objects which are submitted to the police laboratory for x-ray examination because of their

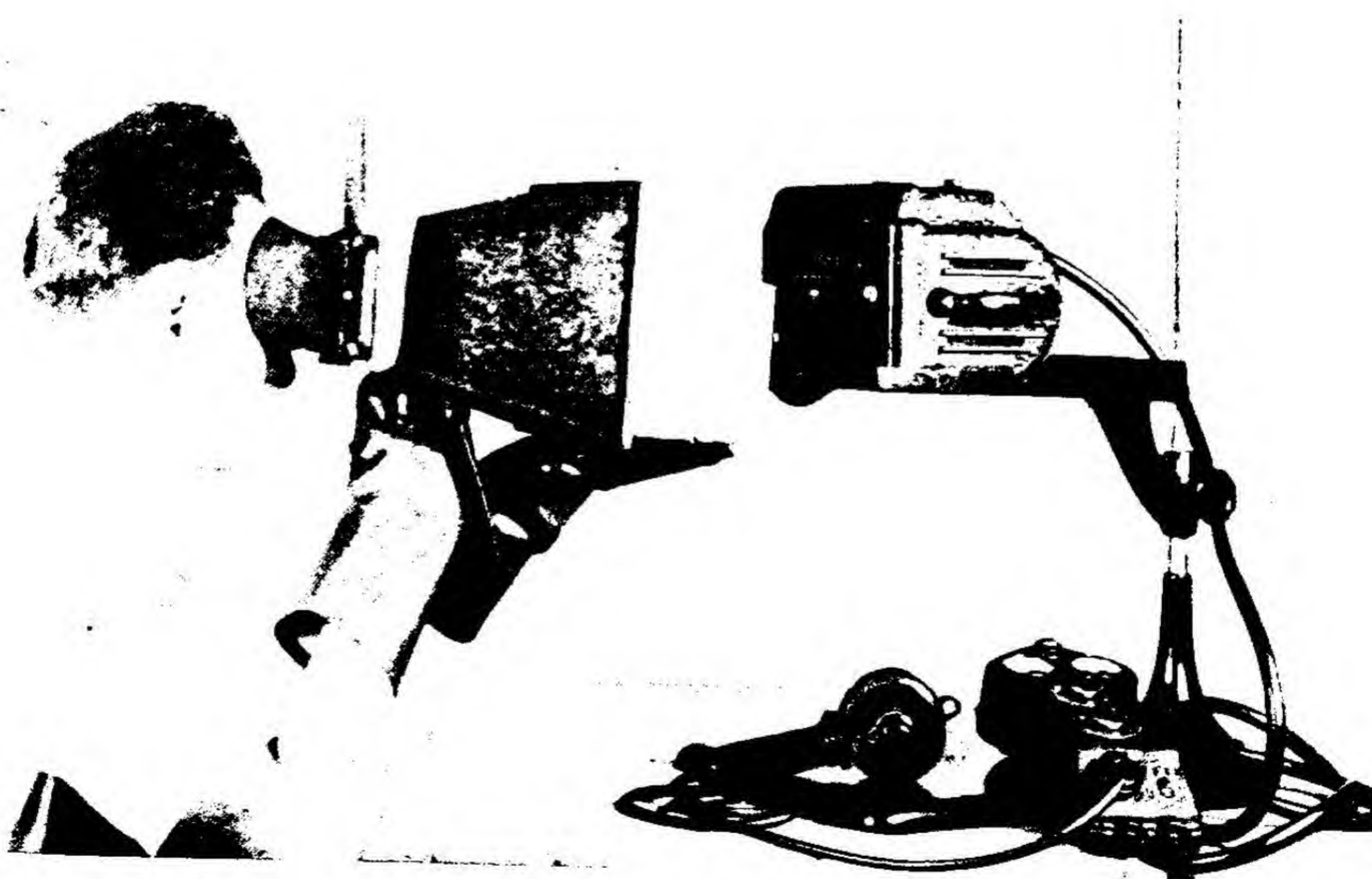


Fig. 171. Fluoroscoping a "suspicious package" with a portable x-ray outfit. The lead apron and gloves are worn for protection.



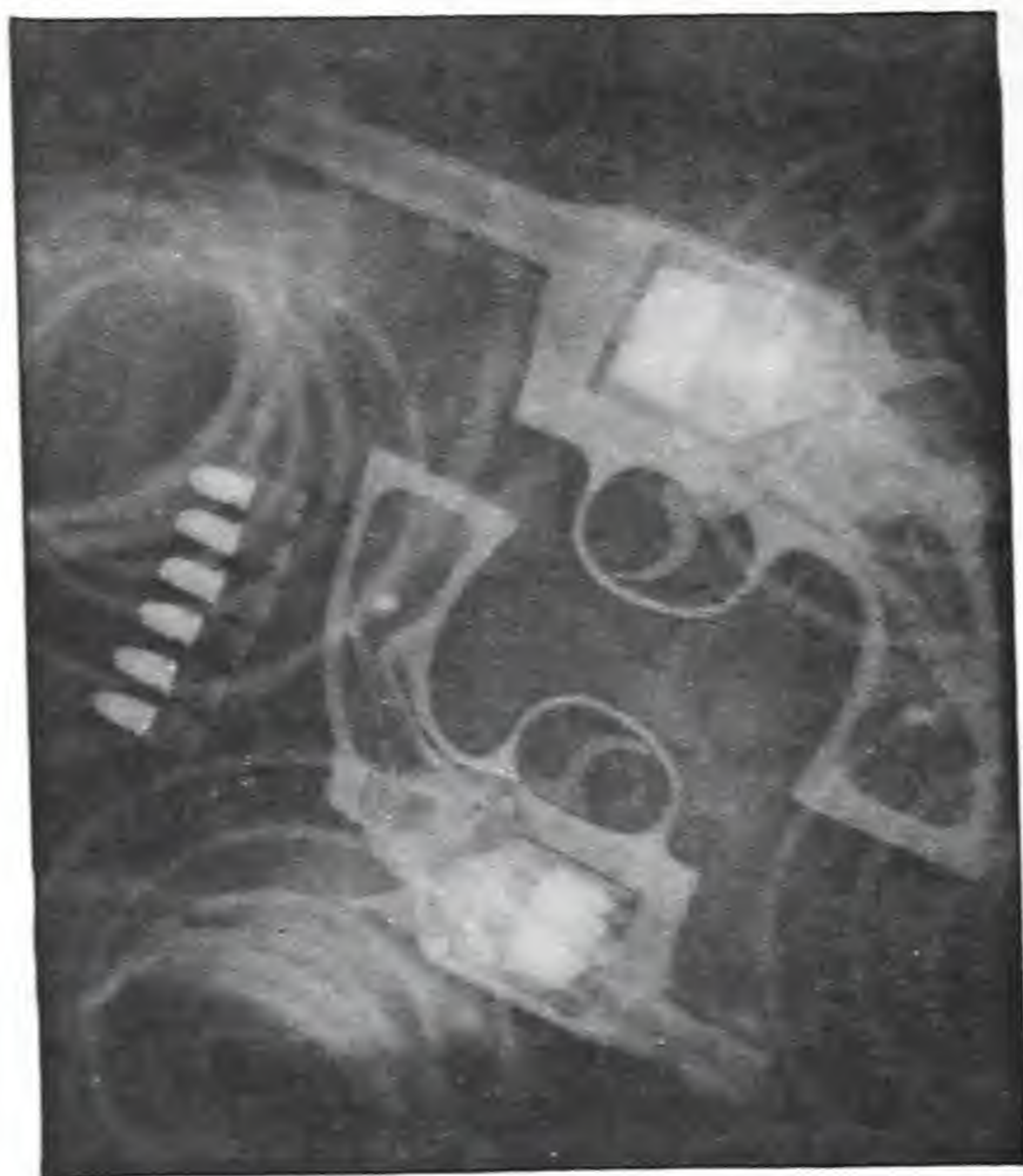


Fig. 172. Radiograph of an upholstered chair in which are concealed several weapons.

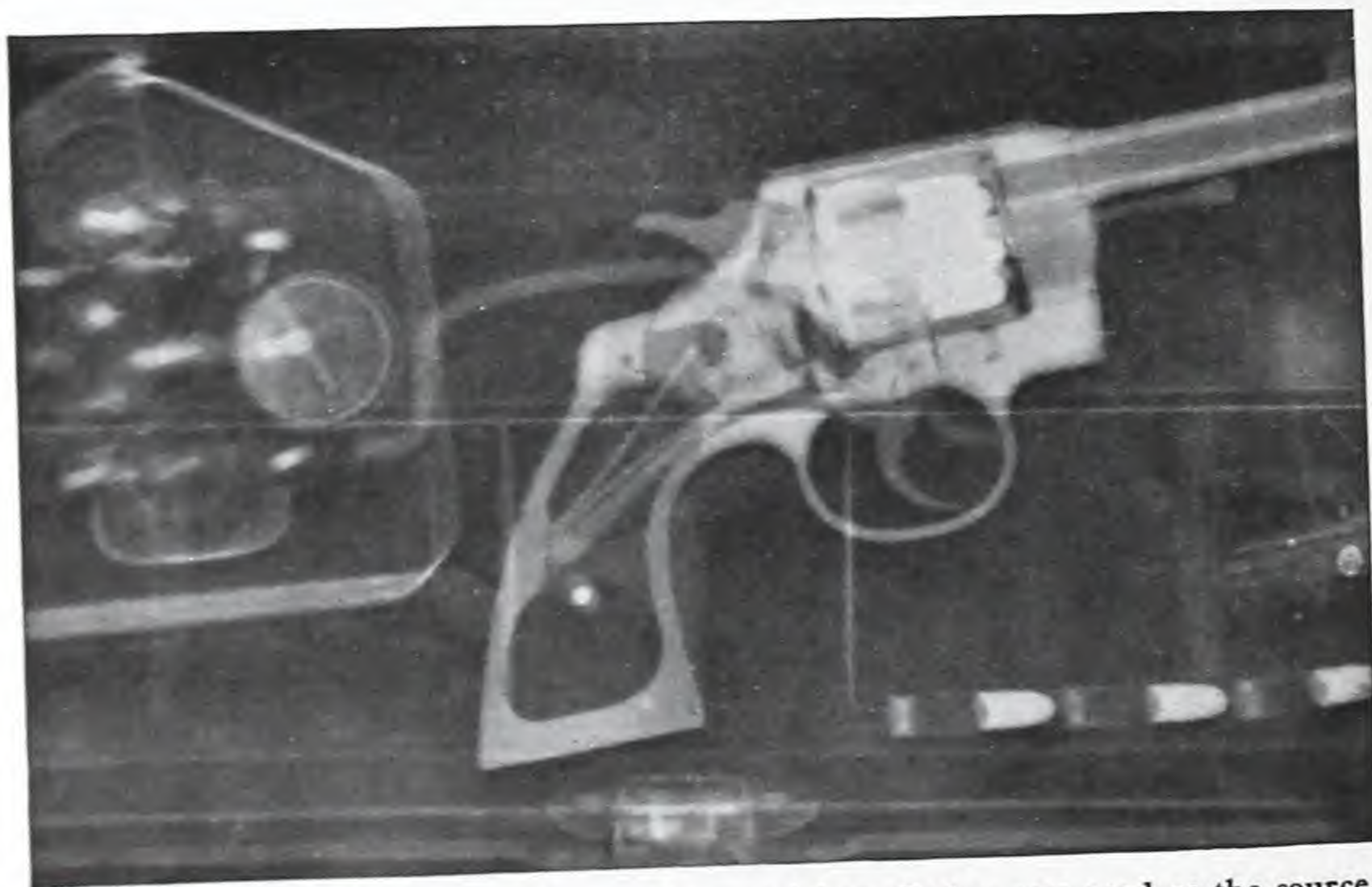


Fig. 173. Radiograph of the contents of a metal box. Radon was used as the source.



varied and frequently unknown nature. However, the salient information for a few typical cases is listed in Table 9. This should serve as a first approximation to indicate the settings which might be employed in similar situations.

**TABLE 9**  
**Hard x-rays (50-140 kv)**

	FLUOROSCOPY <sup>21</sup>	RADIOGRAPHY	
		Suspicious Packages	Loaded Dice
Tube Voltage	50-140 kv <sup>a</sup>	Highest kv possible <sup>b</sup>	65 kv
Tube Current	1-10 ma	1-15 ma	10 ma
Tube-Film Distance	6-24 in.	6-48 in.	22-24 in.
Exposure Time	—	2 sec-3 min	10 sec

**Soft x-rays (4-25 kv)**

	FLUOROSCOPY	RADIOGRAPHY			
	Paintings	Paper, Invisible Writings	Textile Fabrics, Powder Marks	Biological Specimens	Paintings
Tube Voltage	18-25 kv <sup>a</sup>	4 kv	4-20 kv	4 kv	10-20 kv
Tube Current	3-7 ma	3-20 ma	3-20 ma	5-20	8-15 ma
Tube-Film Distance	4-36 in.	4-36 in.	4-36 in.	4-26 in.	4-36 in.
Exposure Time	—	1 sec-5 min	1 sec-5 min	1 sec-5 min	1 sec-3 min

<sup>a</sup> In fluoroscopy the lowest kv position is used first, increasing the milliamperage until the object becomes visible. If the maximum tube current for the lowest kv position does not succeed in producing a satisfactory image, the next highest kv position is selected, and the milliamperage reduced to its lowest value and again increased until the desired fluoroscopic image appears. If necessary, this procedure is repeated using the next highest kv position, etc. If the person who is to view the fluoroscopic image accommodates his eyes to the dark, he will be able to distinguish smaller differences in light intensities at a correspondingly lower milliamperage value for the same kv, as compared with the milliamperage required when he fails to presensitize his sight.

<sup>b</sup> The highest kv position is selected because of the increased exposure latitude it affords. The milliamperage and the exposure time that should be employed must be fortuitously selected, but experience and the fluoroscopy data are helpful in the selection of the appropriate settings for making the radiograph.

The usual arrangement of x-ray apparatus is also employed for low-voltage work. However, the method of enclosing the film in a cassette or in a regular film holder is unsatisfactory; even a piece of black paper is useless since, under suitable conditions, the low-voltage rays may record its structure on the film in the same way as though it were being examined.

The simplest procedure for using soft x-rays is to have the apparatus set up in a room which may be darkened during the time of the exposure. In this way, the use of a film holder of any sort is made unnecessary. The object under



TABLE 10

FACTOR	EFFECT ON			
	Penetration	Exposure Time	Focus or Sharpness of Detail in Image	Contrast
Tube Voltage	Higher voltage, greater penetration	Higher voltage, decreased exposure	Definition decreases as voltage increases	High voltage—low contrast. Low voltage—high contrast.
Tube Current	Depends on tube voltage, but at highest kv, increased tube current results in greater penetration	Higher current, decreased exposure	—	—
Focal Spot	—	—	Smaller focal spot, better definition	—
Film	—	Depends on emulsion speed of film used	Finer grained film, better definition	Depends upon film and development
Intensifying Screen	At highest kv and ma, use of screen may result in penetration that otherwise would be impossible	Decreases exposure	Tungstate screens tend to graininess; hence loss of detail in image	Usually increases contrast
Tube-Object Distance	Inversely proportional	Greater distance, longer exposure	Greater distance, greater definition	—
Object-Film Distance	—	*	Greater distance, diminished definition	—
Thickness of Material	Greater thickness, more difficult to penetrate	Greater thickness, increased exposure required	—	—

\* Since the energy falling on unit area decreases as this factor increases it appears that the exposure time would have to be increased. However this factor is always kept at a minimum and would never be used to influence the exposure time.



examination is placed on, and in direct contact with, the film. If it is necessary to make the exposure in a lighted room, a Wratten 87 (gelatin) filter is placed over the film, and the object is placed on top of the filter. A specially prepared paper of uniform density has also been developed for use in place of the infra-red filter.

### EXERCISES

1. Prepare a suitcase to simulate the interior construction of a bomb. Fluoroscope this package and then make several radiograms, varying the many factors which influence the quality of the finished radiogram. Compare the results obtained and list those factors which need careful consideration if one is to obtain a satisfactory radiograph of an unknown package in the first attempt.
2. Select a genuine coin and its counterfeit. Make a radiograph of the two coins and determine from the difference in density of the negative which is the genuine coin.
3. Repeat the preceding exercise with a true and false pearl.
4. Obtain samples of soft and lead glass (several samples of each). Differentiate among them, if possible, by means of a radiograph.
5. Radiograph a pair of loaded dice and locate the loaded side.
6. If a low-voltage x-ray unit is available, prepare or obtain several samples of the typical evidence materials listed. Make radiographic examinations of these materials and note any information obtained in this manner, particularly if it is not obtainable by other laboratory means.

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# CHAPTER 23

## EXAMINATIONS IN AUTOMOBILE ACCIDENTS

In the police departments of most large communities a special unit or squad is established for the investigation of motor vehicle accidents, particularly one in which a person has been killed. Such investigations ordinarily include a general study of the traffic conditions at the scene of the accident. An excellent treatment of this subject is given in *Accident Investigation Manual*, Northwestern University Traffic Institute, Chicago, Illinois. Many phases of an inquiry of this nature are not related to the duties of the laboratory personnel. There are, however, two outstanding problems in such an investigation that require the services of a person trained in the physical sciences: (1) Establishing the identity of the vehicle in a hit-and-run accident; (2) determining by means of skidmarks the speed at which a vehicle was traveling at the time of an accident. The first of these problems is the subject of the present chapter. The investigation is divided into three phases: (1) the scene of the accident; (2) the injured persons; and (3) the suspected vehicle.

### 1. EXAMINATION OF THE SCENE

A thorough search of the whole terrain should be made. The area surrounding the place where the accident occurred should be isolated until this examination has been conducted. The search for clues should not be restricted to a few yards surrounding this spot but should extend a considerable distance along the road. The following traces should be particularly observed.

#### **Skidmarks**

These marks will give an indication of the point at which the brakes were applied. They are also indicative of the speed at which the vehicle was traveling. An extensive treatment of this subject is given in Chapter 25.

#### **Tire Marks**

Tire impressions in mud, dirt, snow, or tar, and tire prints on a wet roadway contribute very valuable evidence. It is possible to determine the brand of the tire and sometimes to identify the tire itself from characteristic defects (Chap. 9).



### **Dirt from Impact**

The undersurface of the fenders of an automobile is usually caked with mud and dirt. In colliding with a vehicle or even with a pedestrian, some of this dirt will be shaken loose and will fall on the roadway. Samples of this dirt should be collected and preserved for a comparison with the dirt from the undersurface of the fenders of a suspected vehicle. A spectrographic analysis is appropriate. The comparison will contribute to the evidence only if there are some elements or substances in the dirt which are highly characteristic. It is seldom, however, that such evidence is conclusive because of the wide variety of soils over which a vehicle travels in collecting such dirt under the fenders.

If the mud or dirt has fallen in fairly large pieces, the shape of these pieces may become significant. It may be possible to find cavities in the dirt remaining on the fenders or outlines which will correspond to the fallen pieces.

### **Cloth**

If the injured person was run over by the wheels of a heavy vehicle, it will sometimes be found that small fragments of cloth have been removed and are found in the roadway usually in the path of the skidmark. These fragments should be collected as evidence. In subsequent examinations of suspected vehicles, close scrutiny should be given to the tires in order to discover similar pieces of cloth or fibers of the same material.

### **Blood, Tissue and Hair**

The presence of these substances on the roadway at the scene of the accident is usually helpful in suggesting what evidence is to be expected in the future examination of a suspected car. Ordinarily it is not necessary to preserve blood tissue, or hair. Sometimes, however, particularly when these things are found at some distance from the body, it may be helpful to preserve this evidence. In Chapter 4 methods for the collecting and preserving of blood and tissue are described.

### **Chipped Flakes of Paint**

Small flakes of paint are sometimes found at the scene of an accident, especially in collisions between two cars and in accidents involving an old car on which the paint has begun to flake in some spots. All samples of paints at the scene should be collected in order to make possible a future spectrographic analysis with the paint of a suspected car. Flakes should be preserved intact, since it may be possible later to show that the flake fits the outlines of a certain area of the bare metal surface of a suspected vehicle.

The evidence most commonly found at the scene of an accident is glass fragments from the head lamps. The importance of this evidence can hardly be overestimated. Chapter 24 has been devoted to a treatment of this subject.

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### Broken Equipment

Sometimes an ornament or accessory such as the side mirror, head lamp, or radiator emblem is detached from the automobile by the force of the impact. If the corresponding piece of equipment is missing from the suspected car, a photograph should be made showing the part found at the scene together with the area from which it was detached so that the exactness of the correspondence can be established (Figs. 174 and 175).

## 2. EXAMINATION OF THE INJURED

### Clothing

If it is possible, the clothing of the victim of the accident should be examined before it is removed from the body. If the tires have traveled over the body, the direction of motion of the car is sometimes indicated by the manner in which the clothing is pulled together by the contact. The side of the car which struck the person can also be deduced from the evidence.

After the clothing is removed it should be subjected to a thorough scrutiny.

A search should be made for the following traces:

**Grease** — The presence of grease stains may indicate contact with the understructure of the car. An analysis of the grease itself in order to compare it with grease from suspected cars is usually not very profitable.

**Paint** — The clothing should be carefully examined for traces of paint from the vehicle. Metal articles such as buttons, buckles, and ornamental pins are the most likely sources of such evidence. Small particles of paint thus found can be analyzed spectrographically and compared with paint from a suspected car.

**Tire Marks** — In some cases tire marks are detected on the clothing of the victim. Discontinuities of the mark will be found due to the "grabbing" action of the rotating tire which gathers the garment into folds. Distinct impressions are not common since worn tires or dark clothing will give only a faint impres-



Fig. 174. Radiator emblem. The right part was found at the scene of a hit-and-run accident; the left part remained on the vehicle.

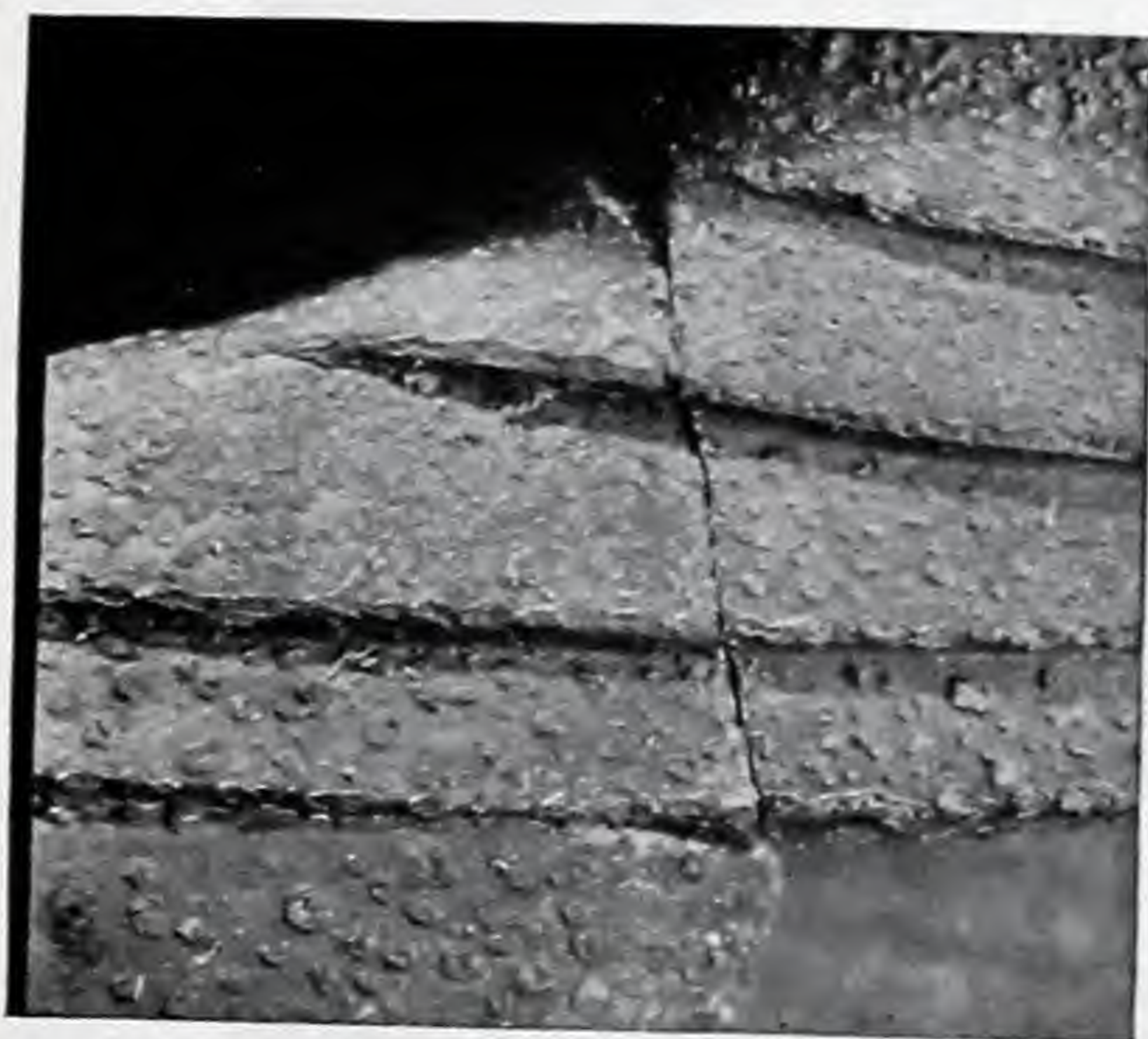


Fig. 175. Photomicrograph of the fracture shown in Fig. 174.



sion. Figure 176(a) shows a tire mark found on a trouser leg. The mark was made by the tire shown in Fig. 176(b).



(a)



(b)

Fig. 176. (a) Tire marks on the trouser leg of a hit-and-run victim; (b) the tire which made the mark shown in (a). The side markings of the tire produced the impression on the trousers.



### Marks on the Body

The nature of the victim's injuries should be ascertained from the attending physician. Frequently the injuries will indicate the part of the car by which the



Fig. 177. A tire mark on a body.

victim was struck. This information will be helpful in examining a suspected car for blood stains. If the wheels of a heavy vehicle have traversed the body, distinct tire marks may sometimes be seen. Figure 177 is a photograph of a tire mark made by a heavy truck. In Fig. 178 the type of tire is shown. The victim had worn a shirt and a sweater at the time of the accident. No identifiable tire mark could be discerned on the clothing.

### 3. EXAMINATION OF THE SUSPECTED VEHICLE

In hit-and-run cases it is frequently requested that laboratory personnel examine a vehicle which has been detained on suspicion. The car or truck may have been picked up by detectives through the aid of the descriptions of witnesses. The driver usually denies being near the place of occurrence. A high degree of uncertainty concerning the identity of the car may exist because of the untrained observation and faulty memory of the bystanders. The investigator is thus faced with a problem which is rarely simple and often very difficult.

It is seldom that convincing physical evidence is discovered by an examination of the vehicle. We should not



Fig. 178. The tire which made the mark shown in Fig. 177.



expect the automobile to bear obvious evidence of a collision with a pedestrian. In the usual accident, the car collides with the pedestrian and throws him in the air and to the side. The car may not show any clear marks of the collision. There may be no blood or flesh on the front of the car because the impact was momentary and the body protected by clothing. In addition to this, the car may bear the marks of many previous collisions, thus bringing the relative freshness of the newer scars into question. These are the difficulties; we discuss now the possibilities.

### **Broken Glass**

If the headlight lens is broken, the remaining glass fragments, however minute they may be, should be removed for comparison with glass fragments found in the roadway.

### **Broken Equipment**

If a radiator emblem, side mirror, or other part of the car is broken off and a corresponding part has been found at the scene, the remaining part should be removed from the car so that it can be photographed at the laboratory. Where this cannot be done conveniently an impression of the area from which the part was detached should be made by pressing a piece of modeling clay against it.

### **Dents, Scratches, and Other Damage**

In a collision between a vehicle and a person the area of contact is usually at the front of the car — the fenders, head lamps, and grill. If the victim is thrown upward, the hood, sides of the fenders, the windshield, or the side mirror may show signs of the impact. If the head lamp is not of the built-in type, its base should be examined for any signs of a displacement or loosening of paint or screws. Damage at the front of the car is usually explained by an untruthful defendant as the result of some minor collision with another car. The recency of scratches and dents is not easily established; however, where the owner of the car claims that such damage was caused a week or so previous the matter should be investigated. The extent of rusting should be examined. Tests should be conducted, if possible, to determine the approximate period of time required for this accumulation of rust with relation to the weather conditions to which the car has been exposed. The weather conditions associated with the period of time preceding the accident should be taken into consideration. In order to prepare for this kind of examination, the investigator should conduct a series of tests of this nature with automobile metal.

Certain kinds of damage are difficult to explain away as being due to an ordinary collision of vehicles. Dents on the top of the hood, or on the top of a fender are rarely due to a casual collision of cars. Damage to head lamps and radiator grill may be caused by colliding with the rear of a truck. A dent, however, on the front of a fender between the head lamp and the radiator is not easily explained, if there is no accompanying damage of the head lamp and radiator at the same level.



### Fibers

The violent contact between car and clothing may leave some fibers on the car which can be identified as similar to those of the victim's clothing. Fenders, bumper, hood, grill, door handle, hinges, head lamps, springs, etc. should be examined, but too much importance should not be attached to the mere finding of fibers here unless blood or flesh is found at the same spot, since the wheels are constantly throwing dirt against the fenders and the matter found here includes samples from a fairly broad section of the countryside. When the vehicle has traveled but a short distance since the accident, say, one hundred yards, the tires may sometimes yield clothing fibers if the victim has been run over. When a collision has taken place between a vehicle and an animal, such as a horse, on the front of a vehicle there will usually be found a considerable number of the animal's hairs. These should be removed and compared with samples taken from the animal.

### Cloth Marks

Although no fragments or fibers of clothing are found on the vehicle, marks of the clothing may still be present at the area of impact. The violent contact between the fenders and the clothing of the victim is sometimes evidenced by an outline of the weave of the cloth. Figure 179 is a photograph of such a cloth pattern on the fender of a maroon-colored car. Figure 180 is a photograph of a sample of cloth taken from the pants of the victim. A comparison of the number of lines per inch revealed that this

cloth would have made the impression on the fender. This impress of the cloth on the paint surface of the car usually has the appearance of a greasy film as though this grease had been pressed out from the cloth. Oblique lighting should be used to produce the necessary contrast. A ruler must be included in the photograph. A thread counter may be used in counting the lines per unit length on the cloth.



Fig. 179. Cloth pattern on the fender of a hit-and-run vehicle.



### Blood and Human Tissue

In most accidents the victim is knocked to one side and does not begin to bleed until there is no longer any contact with the vehicle. However, in head-on

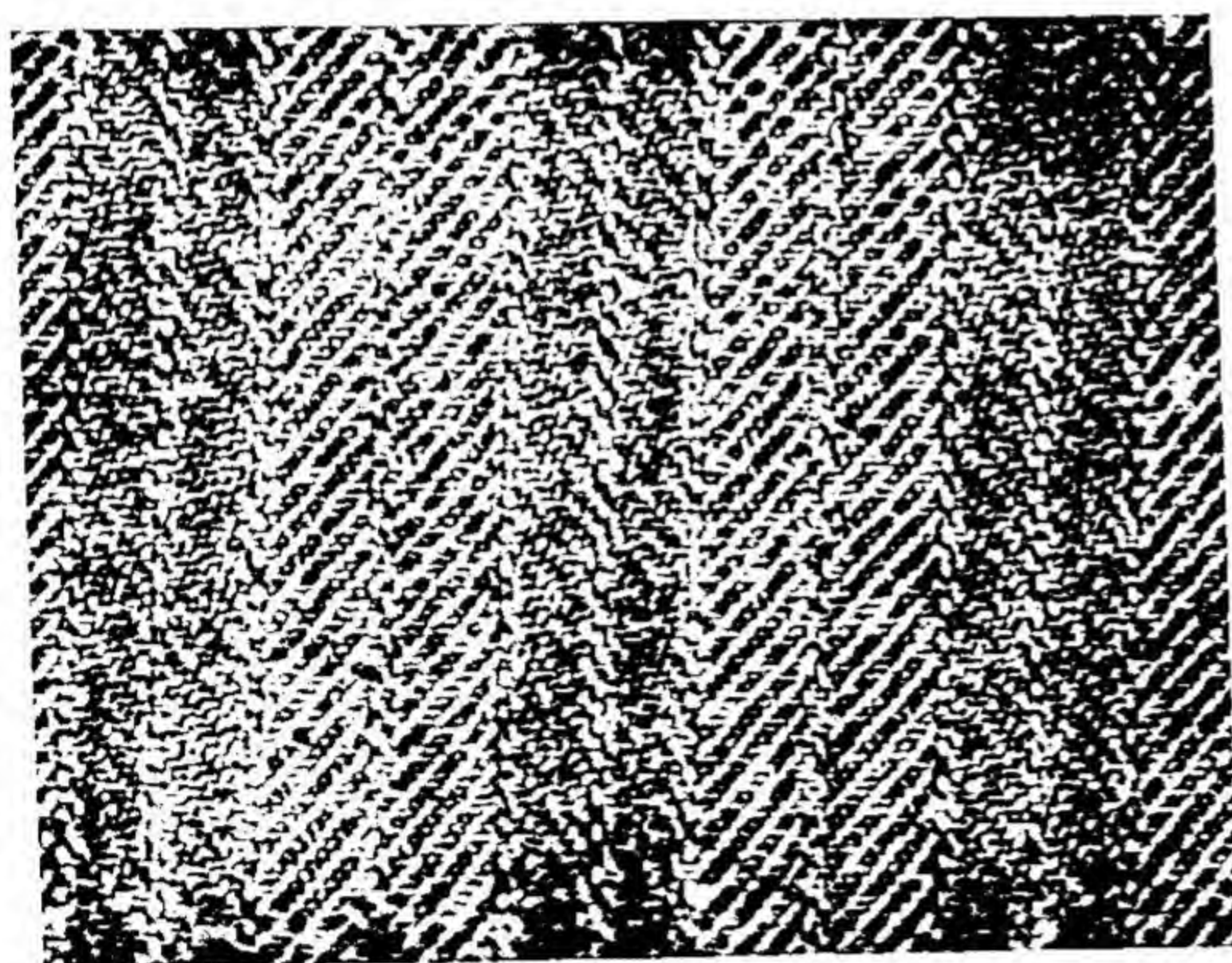


Fig. 180. A part of the victim's trousers. The pattern matches that of Fig. 179.

collisions the victim's body may suffer penetration by projecting parts of the vehicle, and blood and human tissue will be present. It is difficult in any case to obtain a sample of blood sufficient for grouping purposes.

Suspicious stains should be scraped and treated with the benzidine reagent. If the reaction is positive, the possibility of this being due to the paint (where the stain was on the painted surface) should always be kept in mind, and separate tests should be performed with the paint alone.

Samples, of course, should be taken of human blood or tissue wherever it is found. The procedure described in Chapter 4 should be followed. The height of the bloodstains above the ground should be measured and recorded. Low blood stains on the vehicle may be due to striking an animal.

### Characteristic Soil

If the accident has taken place on an unpaved or inadequately paved roadway, the soil may cling to the tires or the inside of the fenders, especially in wet weather. If this soil possesses any highly characteristic elements, a spectrographic analysis will prove useful.

### Understructure of the Vehicle

For a complete examination of the car, it should be taken to a service station and jacked up so that its understructure can be thoroughly examined. On the under surface of any vehicle there will usually be found a considerable number of hairs and fibers that have been picked up over a long period of time. These fibers will usually be of no value unless they are found near blood or tissue.

Any disturbance in the grease on the understructure should be noted. This may have been caused by contact with the victim's body. The clothing of the injured person should be examined for a grease stain. The width of this stain should be measured to see if it corresponds roughly to the area from which the grease has been removed. A pattern of the cloth may sometimes be found in the grease.

### Temperature

When a suspected car has been found a short time after the accident and the owner states that the car has not been driven within the last few hours,



temperature readings of the water in the radiator should be made. If this temperature reading differs considerably from the temperature of the surroundings it is an indication that the car was recently used. The tests should then be made to determine the time which would be required for the water to cool to this temperature after it has been driven for ten or fifteen minutes. This time should be compared with the time which has elapsed since the accident.

If the cooling experiment is conducted at a later date, the temperature of the air should be recorded, since the rate of cooling is proportional to the temperature difference. An expert testifying in a matter of this nature should be aware of the Stefan-Boltzmann law and Newton's law of cooling.

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# CHAPTER 24

## *THE IDENTIFICATION OF AUTOMOBILE AND OTHER GLASS*

### **1. AUTOMOBILE GLASS**

Motor vehicle accidents in which the driver leaves the scene of the accident before identifying himself represent a good percentage of the serious crimes with which the laboratory deals. The nature of these crimes is such that the evidence on which the detectives must rely is mainly physical evidence. Eyewitness testimony is of little value unless the number of the license plate was noted. A common, yet valuable, type of physical evidence in these cases is broken glass which has fallen from the headlight lens. From this glass it is frequently possible to determine the type of lens and from this fact the year and type of car involved in the accident. This is often a simple matter when dealing with cars of older manufacture. Before 1939 different manufacturers of cars used different types of headlight lenses. Several hundred different types of lenses were used on these cars. Unfortunately for criminalistic purposes, the tendency in recent years has been to equip cars with a standard type headlight — the “Sealed Beam” headlight unit. Thus, with each passing year it becomes more difficult to determine the type of car from the lens with which it is equipped.

It is for this reason that the physical properties of glass are becoming of increasing importance to the police scientist. By means of these properties an individual headlight lens can often be identified as the source of the glass fragments found at the scene of an accident. Hence, although in the future cars may be equipped with but one type of lens, these differences of physical properties in the individual lens will always remain as invaluable evidence.

### **2. OTHER GLASS**

Although emphasis in this treatment is placed upon automobile glass because of the importance of hit-and-run cases, broken glass will often be a leading clue in other types of cases. In the commission of a burglary it is frequently found that a window has been broken and the area near the window is littered with glass fragments. The criminal in breaking the window may come in contact



with the glass and catch in a trouser cuff, pocket, or shoe small pieces of glass. Similarly, broken bottles, drinking glasses, or spectacles found at the scene of an assault or other crime of violence should suggest to the detective an examination of the soles and heels of a suspect for imbedded fragments. Although the treatment below will assume that the glass in question is from a headlight lens, the reader should understand that the procedures are applicable also to any other type of glass.

### 3. GLASS FOUND AT THE SCENE

If glass fragments are found at the scene of a hit-and-run accident and no suspect automobile has been discovered, the investigator endeavors to deter-

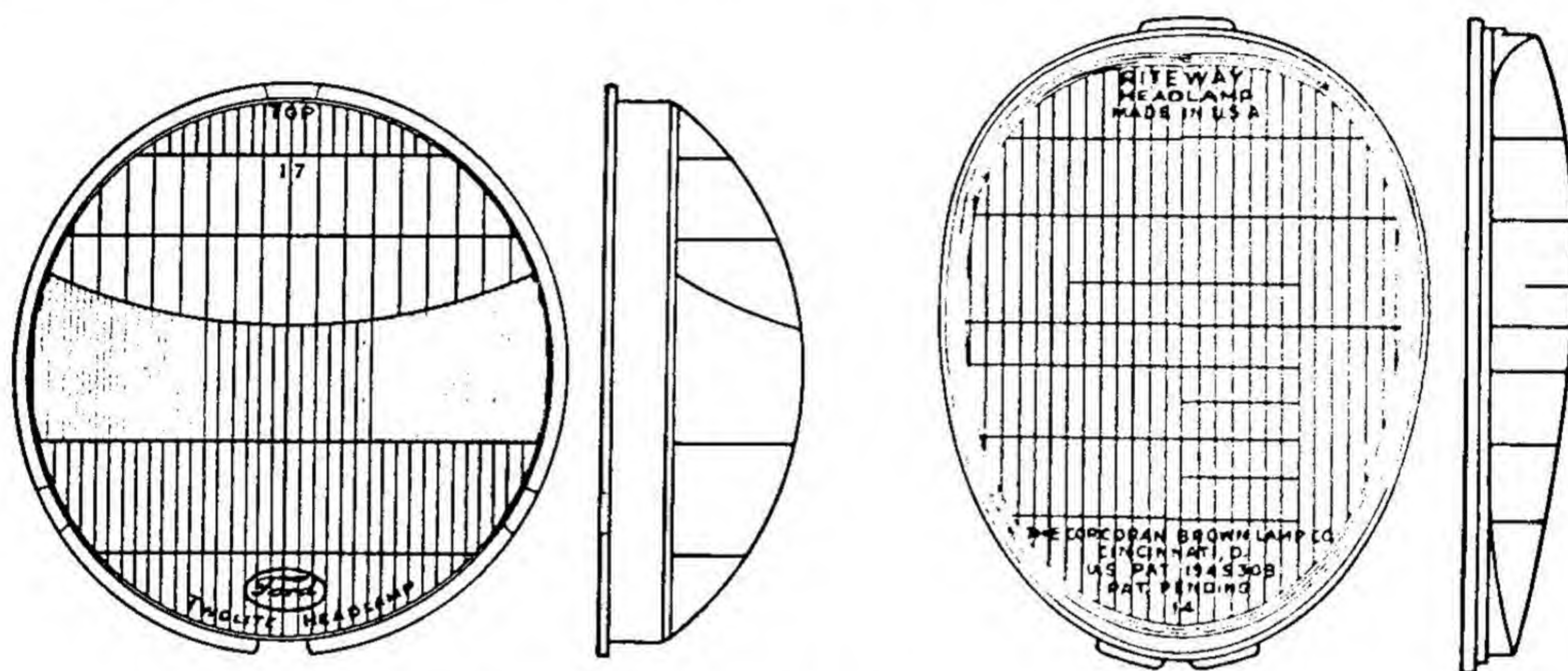


Fig. 181. Front and side view of typical auto lenses.

mine the type of headlight lens with which he is dealing and the make and year of the automobile of which this lens is a standard part. The fragments must be pieced together as in a jig-saw puzzle. To facilitate this procedure, transparent tape should be used to hold together pieces that are found to match. It will be found that a lens usually bears the trade name, the name of the manufacturer, the city or country wherein it is produced and sometimes a patent number (Fig. 181). This information is found above the lower rim of the glass. Near the upper rim of the lens the words "top," "right," "left," or a mold number may be found. The laboratory should possess an adequate collection of the most common types of auto lens. The pieced fragments should then be compared with the (whole) intact lens (from the collection). If a conclusion can then be reached, lens catalogues should be consulted. In these catalogues will be found the make and model of automobiles which carry this lens as original or replacement equipment. This information will in some cases be of great assistance to the detective in limiting the search; in other cases — all too frequently — the data will be found to be too general to be useful, as in the case of "Sealed Beam" headlights which are used on many types of cars.

Matters are seldom as simple as they appear from the procedure outlined in the preceding paragraph. Frequently, the fragments of the lens bearing the



information are missing and only a few pieces can be fitted together. In this case an extensive search through the lens collection must be undertaken. A

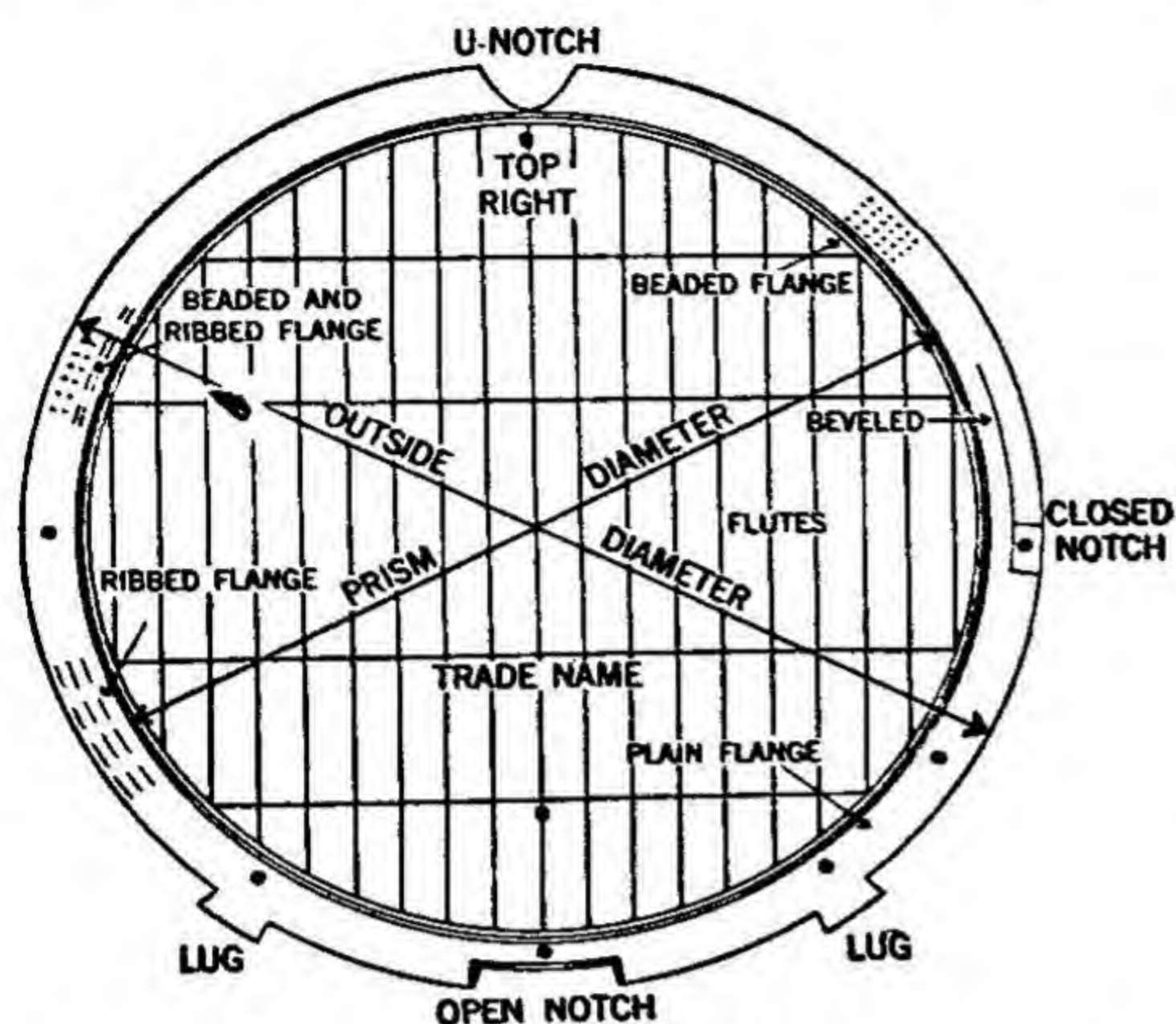


Fig. 182. Auto lens data. (After a drawing from the New York State Bureau of Criminal Identification Bulletin.)

familiarity with the collection will be found helpful in shortening the search. The design of the lens will limit the possibilities, but often five or more choices may present themselves. The curvature of the surface of the lens may be of some value at this point. The spherometer or the Geneva gauge can be used in comparing curvatures (Chap. 6). This should be done along the same meridian in each trial because the curvature of the lens is usually different in different directions. These measurements should be looked upon only as gross approximations, and should be abandoned as a guide when only small differences

are the deciding factor in choosing among a few similar lenses.

An invaluable supplement to a lens collection is a set of photographs of the lenses. These photographs should be taken at actual size. Both the front and side views should be given. This photographic catalogue can be cross-indexed in several ways, e.g., according to size, prism shape, manufacturer, etc.

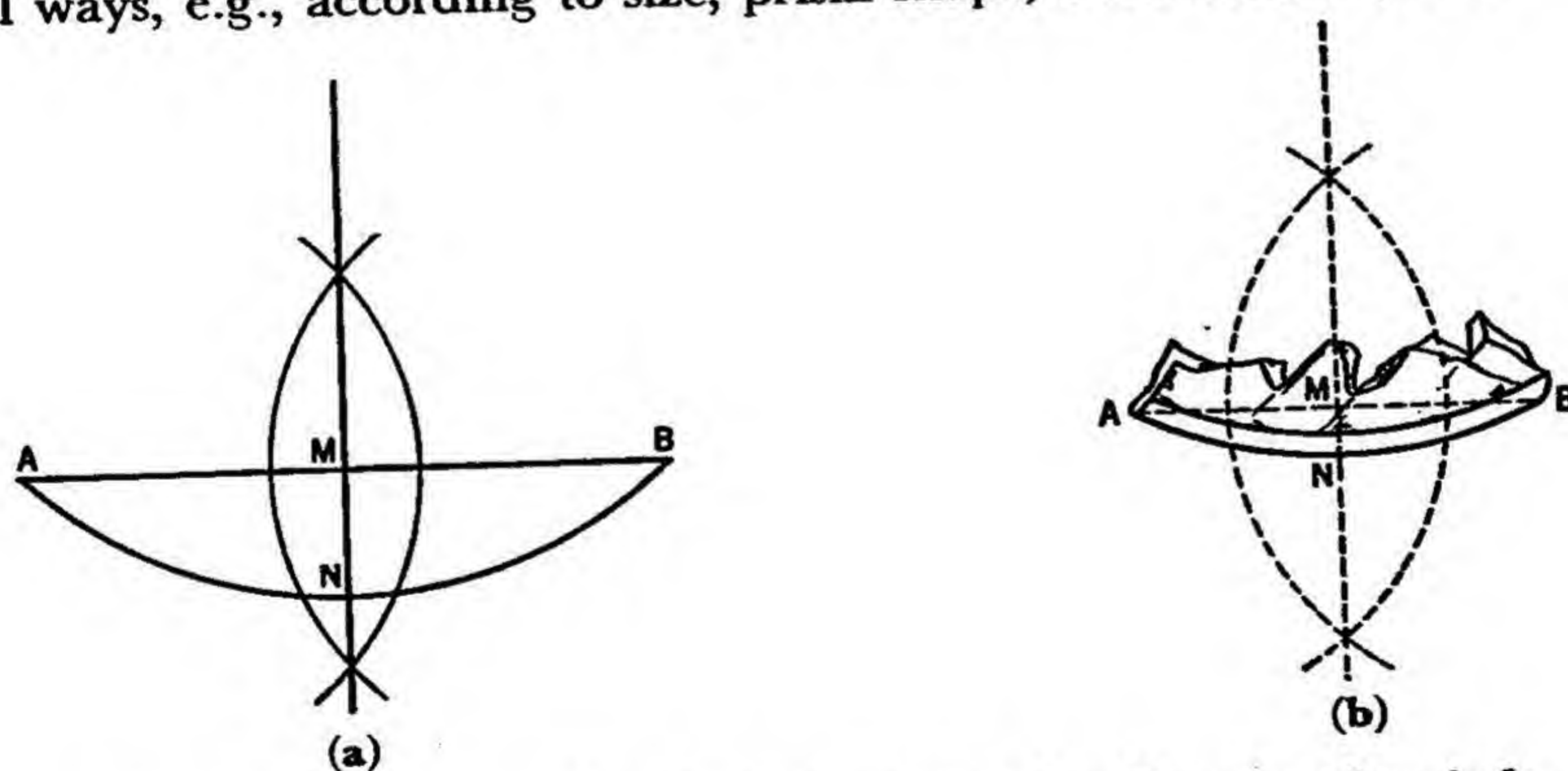


Fig. 183. (a) Construction for determining the diameter of a circle from its arc; (b) the construction applied to a lens fragment.

In comparing the lens fragments with a lens selected from the collection, it is well to fix attention upon certain points. The location of notches should be noted. The flanges should be compared for beads, ribbing, or beveling. The prism must be studied and the fluting examined together with the general convexity or concavity of the lens.

In the case of a circular lens where pieces of the rim of the lens are present,



an approximation may be made of the diameter of the lens. This is of some value in identification by means of the catalogues, which usually list lens diameters. The Geneva gauge will give a rough approximation. The roughness of the approximation is due to the method of manufacture of an automobile lens. The Geneva gauge is properly used only on ground glass or other precision-made material. The following geometrical construction will also approximate the diameter.

Using as a guide the fragments of glass that form a continuous portion of the periphery, trace the arc of the circle with a pencil on a large sheet of paper. Draw the straight line  $AB$  in Fig. 183 connecting the extremities of the arc. On this chord erect a perpendicular bisector. This may be done by placing a compass at  $A$  and drawing an arc of radius exceeding one-half of  $AB$ . Repeat this on point  $B$ . Connect the intersections of these arcs. Measure the distance  $AM$  and  $MN$ . Since the perpendicular from any point on a circle to a diameter of the circle is the mean proportional between the segments of the diameter, we can calculate the diameter  $D$  from the expression

$$D = \frac{AM^2}{MN} + MN \quad (1)$$

Since  $MN$  and  $AM$  are usually relatively small quantities, this construction yields only a rough approximation which is, however, useful in discriminating among lenses the diameters of which differ by a half inch or more.

When the type of lens is finally determined, a satisfactory mode of demonstration in court should be considered. One means of presentation is to make a plaster cast from the sample lens in the collection. The glass fragments can then be mounted in their proper positions on this cast and held together by scotch tape or other means. Figure 184 is a photograph of such a cast.



Fig. 184. Auto lens fragments mounted on a plaster cast of a similar lens.

#### 4. SUSPECTED CAR HELD FOR COMPARISON

If an automobile is discovered in which fragments of the lens can still be found, a comparison may be made with the fragments found at the scene of the accident. To avoid confusion, each fragment from both sources should be first carefully labeled. The fragments from the scene should be pieced together separately; similarly, the fragments from the headlight should be matched among themselves. An attempt should then be made to find pieces from one source to match with pieces from the other.

Frequently, only one or two pairs of fragments are found to match, but the



fit is not evident to the eye and some difficulty may be anticipated in demonstrating the fit to a jury. This difficulty is due to the manner in which the glass is fractured. The break is often along clear straight lines with no characteristic curves evident. The common fracture is most evident in the cross-sectional view. Each surface will have characteristic cross-sectional curves called *rib marks* (Chap. 19). Sometimes a stereoscopic photograph can be made with the matched pieces slightly parted to show the cross-sectional surfaces. The procedure described below will, however, be found more generally applicable.

Select a camera and lens which will give a magnification of about five to one. Place one fragment with cross section parallel to the lens. Illuminate the surface from the side so that the obliquely falling light forms shadows in the curves of the well-developed surface. Photograph the second surface in the same manner without changing the bellows extension (to preserve the same magnification).

When the negatives are finished, enlarged transparencies should be made on 8 by 10 film. The negative is placed in the enlarger in the usual manner and printed on ortho film. Test strips should first be printed since the exposure is not readily predicted. The transparencies are then developed for good contrast. When the transparencies are finished, by placing one over the other in the proper position it is possible to superimpose the characteristic curves so that they coincide. This correspondence, by holding the negatives in front of a strong light and then adjusting one until the curves of one lie over the curves of the other, is suitable for demonstration in the hands of a judge or jury.

In addition to its value in determining the make of car involved in an accident, a headlight lens may also possess other important clues. Sometimes, part of the gasket which is placed between the lens and rim is found adhering to a glass fragment in the street. The remaining part of the gasket will usually be left in the head lamp by the excited driver. A match of these two pieces provides excellent evidence. In the spraying of fenders minute paint specks are left on the headlight glass; hence the discovery of these specks may indicate a car with resprayed fenders and also provide an additional clue in the nature of the paint. Similarly, when the headlight rim is painted with a brush, the marks of the brush are often carried over to the glass itself. The brush marks on a glass fragment may be compared with similar marks on the rim of a suspected car. Further, in painting the rim, drippings sometimes run down along the lens and fall on the ring below. If the lens fragment is properly located on the rim, the paint marks on the lens should be directly over the point where the drops fell on the ring.

## 5. COMPOSITION OF GLASS

It is difficult to provide an adequate definition of the term *glass*. In general, this term describes a state of an inorganic substance rather than a chemical compound of definite composition. We may best describe glass as an undercooled liquid which possesses high viscosity and, hence, rigidity. In order that a substance be suitable for use as glass, it is necessary that it remain in the liquid state



in the temperature region immediately below its freezing point and that it persist in this form at ordinary temperatures.

Glasses are usually composed of oxides such as silica,  $\text{SiO}_2$ ; boric oxide,  $\text{B}_2\text{O}_3$ ; and phosphorus pentoxide,  $\text{P}_2\text{O}_5$ . For commercial uses silica is the most important oxide. In making glass from silica it is necessary to use a number of other oxides for various purposes such as fluxing, chemical durability, and reduction of viscosity.

The important oxides found in various commercial glasses together with their effect on the properties of the glass are listed in Table 11.

TABLE 11

OXIDE	COMMON NAME	PROPERTIES OR FUNCTION
$\text{SiO}_2$	Silica	The base of commercial glasses.
$\text{Na}_2\text{O}$	Soda	Acts as a flux for silica.
$\text{CaO}$	Lime	Gives the glass chemical durability which it would otherwise lack because of the water soluble $\text{Na}_2\text{O}$ .
$\text{MgO}$	Magnesia	Present as an impurity or as a substitute for $\text{CaO}$ .
$\text{Al}_2\text{O}_3$	Alumina	Gives the glass greater chemical durability, lower coefficient of expansion, and greater freedom from devitrification.
$\text{K}_2\text{O}$	Potash	Chemical durability and resistance to devitrification.

Lead oxide, barium oxide, and iron oxide are also used in some glasses.

Glass, such as window and plate, which is made in mass production, is fairly uniform in composition. The mechanical processes involved in glass manufacture on a large scale require considerable control over the composition of the glass. Table<sup>1</sup> 12 gives the composition of some representative samples of glass.

It should be noted that all of these glasses may contain incidental impurities. These may be impurities in the ingredients used in a batch or may be due to pot or tank corrosion. The presence of these extraneous substances is invaluable for the comparison of glass by spectrographic analysis. Frequently these trace elements may be sufficient to establish (or negate) the fact of a common source for two samples of glass.

Although the substances which are used in making a glass are definitely known, the compounds which are actually formed in the glass are a matter of speculation and cannot be determined by the techniques now in use. The methods which have been employed in an effort to determine these compounds are described by Morey.<sup>2</sup> One of his conclusions is that: "The results of many observers on the physical properties of glass at ordinary temperatures indicate that no justification exists for an assertion that definite compounds exist in and determine the properties of glass." <sup>3\*</sup>

\* From *Properties of Glass*, by G. N. Morey, copyrighted 1938 by Reinhold Publishing Corporation.



TABLE 12

COMPONENTS	WINDOW GLASS (19TH CENT. AMER.)	WINDOW GLASS MACHINE CYLINDER (AMERICAN 1920)	WINDOW GLASS FLAT DRAWN (FOURCAULT PROCESS)	POLISHED PLATE GLASS (AMERICAN 1929)	BOTTLE GLASS (AMERICAN)	BOTTLE GLASS (AV. OF 32 DIFFERENT GERMAN GLASSES, 1930)
	GLASS 900 A.D.	HAND CYLINDER				
SiO <sub>2</sub>	68.48	72.26	72.88	71.00	72.68	74.50
Al <sub>2</sub> O <sub>3</sub>	0.70	{1.42}	{0.78}	0.54	0.50	0.81
Fe <sub>2</sub> O <sub>3</sub>	0.91			0.09	0.07	0.09
CaO	5.71	13.34	12.68	11.26	12.95	5.5
MgO	5.28	—	0.22	1.56	—	4.1
Na <sub>2</sub> O	14.95	14.01	12.69	15.13	13.17	15.0
SO <sub>3</sub>	0.54	—	—	0.44	0.44	—
K <sub>2</sub> O	2.83	—	—	—	—	—
PbO	0.95	—	—	trace	—	—
As <sub>2</sub> O <sub>3</sub>	—	—	—	—	0.18	—
Sb <sub>2</sub> O <sub>3</sub>	—	—	—	—	—	—
MnO	—	—	—	—	—	—
ZnO	—	—	—	—	—	—
B <sub>2</sub> O <sub>3</sub>	—	—	—	—	—	—

COMPONENTS	CONTAINER GLASS (FOR JARS)	ELECTRIC LIGHT BULB	VACUUM BOTTLE GLASS	AMERICAN TABLEWARE (LIGHT LEAD CRYSTAL)	LABORA- TORY GLASS (PYREX)	SPEC- TACLE GLASS
SiO <sub>2</sub>	69.10	72.4	71.28	67.2	80.75	69.04
Al <sub>2</sub> O <sub>3</sub>	3.23	0.8	{1.92}	—	{2.20}	—
Fe <sub>2</sub> O <sub>3</sub>	1.93	0.4	3.87	0.9	0.30	12.07
CaO	11.8	5.3	3.19	—	—	—
MgO	1.6	3.7	12.13	9.5	4.10	5.95
Na <sub>2</sub> O	10.8	17.4	—	—	—	—
SO <sub>3</sub>	—	—	1.01	7.1	0.10	11.75
K <sub>2</sub> O	—	—	—	14.8	—	—
PbO	—	—	0.13	0.5	—	—
As <sub>2</sub> O <sub>3</sub>	—	—	—	—	—	0.90
Sb <sub>2</sub> O <sub>3</sub>	—	—	—	—	—	—
MnO	1.55	—	1.21	—	—	—
ZnO	—	—	4.70	—	12.00	0.25
B <sub>2</sub> O <sub>3</sub>	—	—	—	—	—	—

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## 6. ANALYSIS OF GLASS

The problem with which the forensic scientist must ordinarily deal is the comparison of two samples of glass. The following methods of analysis are used:

### Spectrographic Analysis<sup>4</sup>

This is the only adequate method of chemical analysis for forensic purposes. It is also the most rapid means of comparing two samples. Its effectiveness in characterizing a sample, however, depends upon the presence of trace elements. This is due to the fact of the similarity of composition of commercial glasses and the control of uniformity of ingredients which is maintained in the manufacture. In the absence of trace elements it may become quite difficult to determine spectrographically whether two samples of a common type of glass are identical



or different in composition. A spectrographic analysis should in any case be supplemented by measurements of the physical properties.

### **X-Ray Diffraction Analysis**

It is stated in Chapter 42 that x-ray diffraction analysis is not limited to crystalline substances. Diffraction patterns can be obtained also from amorphous substances and even from liquids. Although glass is a liquid, the arrangement of the atoms is not completely a random configuration and consequently gives rise to a definite diffraction pattern. A number of studies of the x-ray diffraction patterns of glass have shown that the type of pattern depends upon the composition of the glass.<sup>5,6</sup> As a method of studying the constitution of glass, x-ray diffraction is second only to measurement of its physical properties. A comparison of the x-ray diffraction patterns of two samples can reveal differences which will reject the hypothesis that the samples are of the same origin. The method is, however, by no means as effective as spectrographic analysis in comparing two glass samples.

### **Physical Properties**

The most sensitive method of determining small differences of composition in glass samples relies upon their physical properties. Density and refractive index are two of the most important properties and have been the subjects of a great number of investigations. Property-composition curves are used as a means of determining the presence of compounds in glass. Although spectrographic analysis will reveal the constituent elements of a glass, it will not yield information concerning the compounds present. It is possible for two glasses to possess the same constituent elements as seen spectrographically and to have originated from different sources, since there may be an insufficient number of trace elements present to distinguish the two samples.

The characterizing properties of a glass depend not only on the constituent elements but also on the manner in which the glass has been treated in the manufacture. Glasses of similar composition possess different properties depending upon the mechanical and heat treatments which they have received. It is for this reason that considerable importance is attached here to physical properties as a means of comparing glass samples. The measurement of these properties has the additional advantage of requiring relatively inexpensive equipment. The conclusiveness of the results is comparable to that obtained in spectrographic analysis. Density and refractive index are sufficient to distinguish between two samples. They can be measured with great accuracy with relatively inexpensive equipment.

### **Density**

The methods of measuring this property have been described in Chapter 7. The flotation method is the most suited to the problem of comparing the densities of the two glass samples. The accuracy obtainable is very great since what is being measured is a density difference and not the absolute density. Differences of the order of  $10^{-6}$  can be observed even though not measured



quantitatively. It is well, however, for the purposes of record to determine the density of the liquid in which the comparison was made. Morey<sup>7</sup> gives a series of tables which illustrate the variation of density with composition for different glasses.

Beeman<sup>8</sup> has noted that particle size is important in determining the specific gravity of glass. He has found differences of the order of  $10^{-3}$  in the specific gravity of large and small specimens. This difference is probably due to the compression of the immersion liquid at the interface, which occurs with samples of large surface. Culbertson and Weber<sup>9</sup> have reported variations in density values with particle size. It is well in making density determinations to use samples (known and unknown) of comparable size.

### Refractive Index

In the manufacture of optical glass great care is exercised to maintain control over the refractive index. At best, the index cannot be controlled within the fourth decimal place in succeeding melts of the same type of glass. To obtain glass of identical optical characteristics it is necessary to use glass from the same melt. With rolled glass, the case is much worse than with pot glass, since the former is made from all parts of the melt. The result is a glass of varying optical characteristics, marked by striae or streaks of different refractive index. Rolled glass, nevertheless, is satisfactory for many optical purposes. Other types of glass with inferior control of refractive index are plate glass, which is polished in large sheets, and window glass, which is blown with little regard for optical characteristics.

The refractive index of a glass can be measured by any of the methods for solids described in Chapter 40. Immersion methods with the microscope will yield results accurate to about one unit in the third decimal place. Greater accuracy is obtainable by means of the Abbé and Pulfrich refractometers. These methods, however, require that the sample be ground and polished. The spectrometer is perhaps the most accurate means of measuring the index, but the method requires a large sample and great care in polishing and shaping.

Extensive studies have been made on glass for the purpose of determining the relationship between refractive index and composition. Naturally, the control of refractive index is a major problem in optical glass manufacture and considerable data have been acquired on this property. Morey<sup>10</sup> gives a series of these studies.

It must be mentioned that two glasses from independent sources can very conceivably have the same index of refraction or the same density but it is quite improbable that they would have *both* index refraction and density the same. A study of the possibility of finding random samples of glass which possessed the same density and refractive index was made by Gamble, Burd and Kirk. The following are their conclusions:

"One hundred samples of glass, collected at random were compared as to their refractive index and specific gravity. All of them were definitely distinguishable on the basis of these properties alone.



"All of the samples could be distinguished on the basis of refractive index alone, but in a few cases the differences were not larger than might occur at times as local variations due to manufacturing imperfections.

"Most, but not all samples could be distinguished from the others on the basis of specific gravity comparisons. In no case were both the refractive index and specific gravity of two samples so close as to lead to possible confusion." 11 \*

### Dispersion

One of the advantages of determining refractive index by means of a refractometer is the readiness with which another important property — dispersion — can then be measured. Two glasses of the same refractive index may possess widely differing dispersions. If  $n$  is the refractive index and  $\lambda$  is the wave length of light, we can define dispersion as  $dn/d\lambda$ ; i.e., dispersion is a measure of the change in the velocity of light in a medium due to a change in wave length. Traditionally the dispersion of optical glass is taken as the ratio

$$\nu = \frac{n_D - 1}{n_F - n_C} \quad (2)$$

where  $n_D$ ,  $n_F$ , and  $n_C$  are the refractive indices of the medium for wave lengths 5896 Å, 4861 Å, and 6563 Å, respectively. Other forms giving mean dispersion and partial dispersion are also used. The value of  $\nu$  can be determined by means of the Abbé and Pulfrich refractometers.

An excellent means of obtaining a photographic record of the dispersion of a sample is by use of the spectrometer. If large samples are available they can be polished and shaped in the form of prisms of appropriate angle. In place of the telescope, a camera arrangement can be set in the path of the emergent rays. It is not necessary (or desirable) to use monochromatic light in these measurements. The use of white light will give a great number of lines on the photographic plate. The matching of these lines in two photographs is conclusive evidence in the comparison of two samples.

### Fluorescence<sup>12, 13</sup>

The known and unknown samples of glass should be examined under ultraviolet light in a darkroom. A difference in the appearance of their fluorescence is indicative of physical or chemical differences.

### Polish Marks

Optical glass and other fine glassware is usually polished. In the polishing of glass fine marks are often left on the surface which can sometimes serve as a basis of comparison. Before examining these marks, the surface should first be cleaned with alcohol and then etched by spraying with 20–25 per cent hydrofluoric acid. The acid is permitted to remain on the surface for several minutes. The glass is again washed with alcohol and dried. If the surface is

\* Reprinted by permission from: L. Gamble, D. Q. Burd, and P. L. Kirk, "Glass Fragments as Evidence," *J. Crim. Law and Crim.*, 33, 416–421 (1943), copyrighted 1943 by the Journal of Criminal Law and Criminology.



illuminated by oblique light a photograph can be made which will show the polish marks.

### EXERCISES

1. Obtain a sufficient number of fragments of a lens to enable an identification by comparison with a lens collection. Using the lens from the collection, make a plaster cast. Place the fragments on this cast and connect contiguous pieces with scotch tape.
2. Examine two adjoining fragments from the same lens, after labeling each piece for identification, photograph them in oblique light to emphasize the rib marks. Make transparencies as described in this chapter.
3. Using the same samples determine the index of refraction of a specimen from each sample. Using a third sample from another source again determine the index.
4. Determine the densities of the three samples used in exercise 3 by the flotation method (Chap. 7). When equilibrium is reached for one of the fragments used, immerse the other two fragments. What are the results?

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# CHAPTER 25

## *DETERMINING SPEED IN MOTOR VEHICLE ACCIDENTS*

The problem treated in the preceding chapter was concerned with the methods of identifying a vehicle as having been the vehicle involved in an accident. This was the case of the hit-and-run vehicle. In the present section we deal with the question of excessive speed. It is assumed that the car has been identified, but that the driver denies that his vehicle was exceeding the speed limit. It is required to determine the speed with which he was traveling. Although in New York and other large cities special squads are established for investigating these accidents to determine culpability and to discover any defects in the mechanism of the vehicle, in many communities this work is considered to be within the province of the police laboratory. A thorough discussion of the causes of automobile accidents would require a complete description of the mechanism of a car and the knowledge of an experienced automobile mechanic. Since, however, most of such accidents are due to defective brakes, failure to apply brakes in time, or excessive speed, we shall discuss here some of the physical principles which govern the behavior of a car during braking.

Our main problem throughout this section will be determination, by means of skidmark measurements, of the speed with which a car had been traveling when a collision took place. The distance within which a moving vehicle can be brought to a full stop depends upon the following mechanical factors: (1) the speed of the vehicle; (2) the nature of the surface of the road; (3) the condition of the road, whether dry, wet, snowy, or icy; (4) the tread design of the tires; (5) the wear of the tires; (6) the degree of inflation of the tires; (7) the effectiveness of the brakes.

Personal factors also affect the time required to stop. The driver must first be aware of the situation and then react properly. Reaction time (simple eye-foot including foot movement) varies with the driver; the average driver, however, has a reaction time of one-half to three-quarters of a second.<sup>1</sup> When it is remembered that at 60 miles per hour a car is traveling 88 feet per second, reaction time will be seen as a very important factor. Since we are examining



here only the physical evidence, we shall not be concerned at all with personal factors but shall confine ourselves to the behavior of the vehicle itself.

In the following treatment an elementary study of the problem is first made and a more general theory then described. A knowledge of the physical principles is essential to anyone who may be called to testify as an expert witness.

### 1. COEFFICIENT OF FRICTION

Friction is the force opposing the sliding motion between surfaces in contact. The coefficient of friction between two surfaces is the ratio of the force necessary for relative tangential motion to the force pressing them together. The product of the coefficient of friction and the normal force (force at right angles to surfaces) is the frictional resistance.

In Fig. 185, to determine the coefficient of friction of the block on the surface  $OM$ , we would tilt the surface until the block just begins to slide down the plane. The angle,  $\alpha$ , at which this motion begins is called the angle of repose. If, from the center of gravity,  $C$ , we draw the line  $CW$  representing the weight of the body, then  $CF$  is the component of weight along the plane  $OM$  and  $CP$  is the component normal to  $OM$ . From our definition of the coefficient of friction

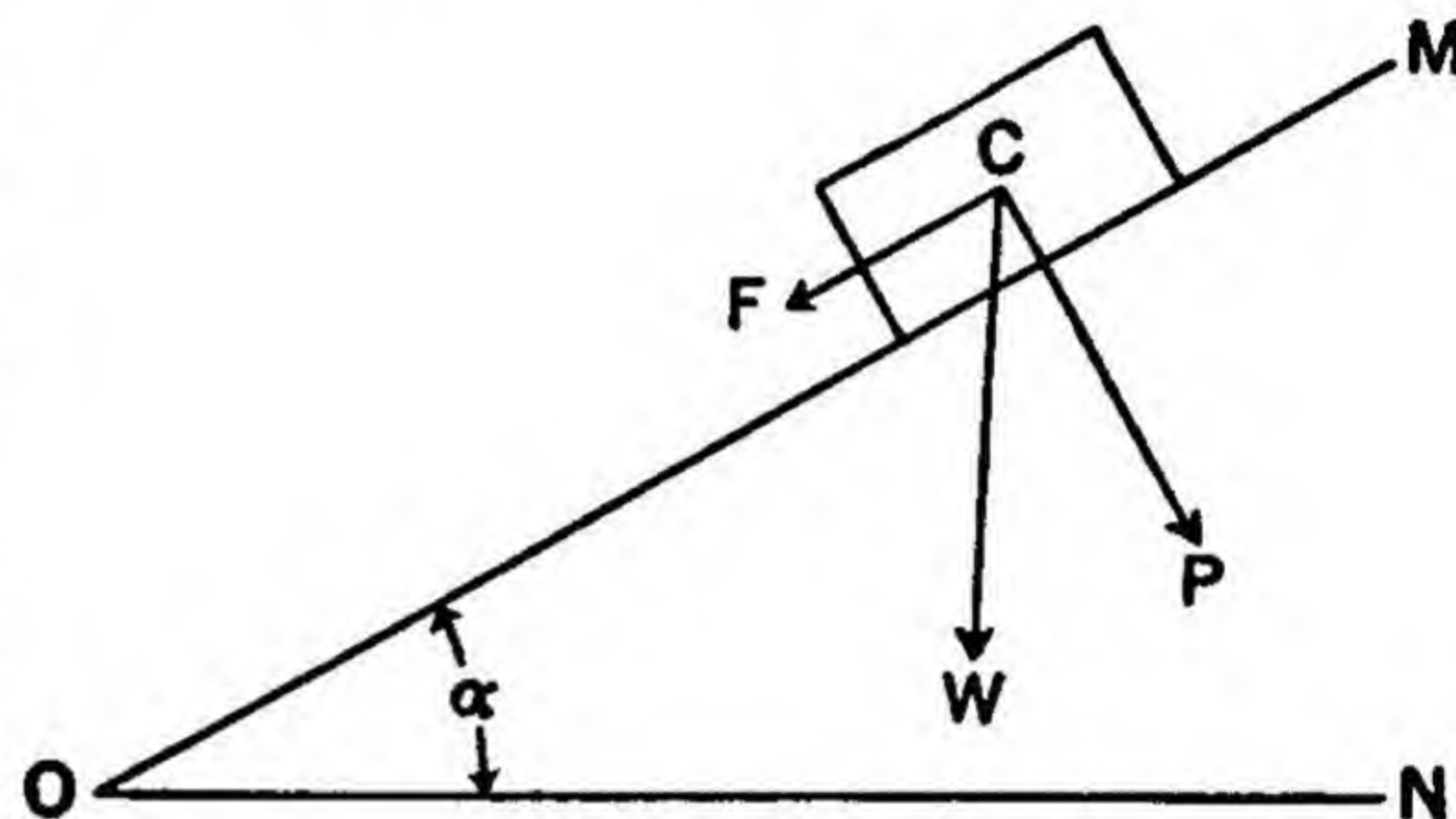


Fig. 185.

$$\mu = \frac{\text{tangential force}}{\text{normal force}} = \frac{CF}{CP} = \tan \alpha$$

(a) Our definition suggests a simple method of determining the coefficient of friction of rubber tires on roadways. The car in question is tied to one end of a dynamometer by means of a rope or chain. The other end of the dynamometer is attached to a rope or chain which in turn is tied to a tow truck. The wheels of the car are locked and the truck is driven to make the car slide over the ground at a constant velocity. The force required to pull the car in this manner is read from the scale of the dynamometer. This horizontal pull divided by the weight of the sliding car will give the value of the coefficient of friction between the tires and the roadway.

For example, if the force,  $Q$ , required to move a 3000-pound vehicle is 2100 pounds as read from the dynamometer, then the coefficient of friction,  $\mu$ , is given by

$$\mu = \frac{Q}{W} = \frac{2100}{3000} = 0.70$$

(b) The coefficient of friction can also be determined by means of equation (2) below, which will be derived later. From this we have

$$\mu = \frac{v^2}{30s} \quad (1)$$



where  $v$  is the speed in miles per hour and  $s$  is the distance of skidding in feet. The vehicle is driven at constant speed and the brakes are fully applied. The distance  $s$  is the full braking distance and not merely the length of the skidmarks.

(c) A third method of determining  $\mu$  involves the use of the decelerometer. The method will be described later. This test is usually not satisfactory on passenger cars because of the effect of weight transfer in a quick stop and the possibility of a sudden jerk causing the recording to exceed the true or average value for deceleration.

(d) Summary. Of the three methods the latter two are usually preferred. The claim is made that the dynamometer reading gives too large a value for  $\mu$ . Since it is desirable to grant the defendant the benefit of any doubt, the smaller values of  $\mu$  are used, and  $\mu$  is determined from the braking distance.

We shall see later that it is not necessary in most cases to determine the coefficient of friction in order to apply equation (1) for our purposes.

## 2. TIRES AND FRICTION<sup>2, 3, 4</sup>

To properly understand the behavior of tires on a roadway the fundamental law of friction must be kept in mind: True friction between two surfaces depends on the force pressing them together. If  $F$  is the true frictional resistance of a tire, then the frictional resistance per unit area is  $F/A$ . The frictional resistance for the area  $A$  in contact with the road is then  $F/A \times A = F$ .

Theoretically frictional resistance between two surfaces is independent of the area of contact; e.g., a tire of 8 inches width would have the same traction as a tire of 4 inches width. This, however, is not strictly true. A distinction must be made between true frictional resistance and mechanical resistance. The total frictional resistance must be defined as the sum of these two. The mechanical resistance is due to the mechanical interlocking between the tire tread and the road surface. When the tire skids there is a shearing off of small particles of rubber which are interlocked with the road surface. This mechanical resistance depends not only upon the normal force but also upon the area of contact.

Various factors affect the frictional resistance of a tire. These are described below. Most of these are minor factors which do not materially affect the results of an investigation.

### Effect of Weight

An increase in the load carried by the tires causes a slight decrease in the frictional resistance. Although the area of contact increases with the load, the increase is not proportional to the increase in weight, so that there is an actual decrease in contact area per unit load which results in a decrease in the mechanical resistance. Another effect of increased weight is to raise the temperature of the tire, thus lowering resistance. Because of this effect of weight, tests conducted on a vehicle should be made with the same load which the vehicle was carrying at the time of the accident.



**Effect of Tire Pressure<sup>5</sup>**

The contact area of the tire decreases with an increase in pressure; hence there is a decrease in frictional resistance for an increased pressure. The coefficient will vary, for example, from 0.7 to 0.5. Again, a vehicle should be tested with the tires at the same pressure which they had at the time of the occurrence.

**Condition of Tires<sup>6</sup>**

Since frictional resistance depends upon contact area we should expect a greater coefficient from the closed type of tire tread than from the open. On dry surfaces it is true that the frictional force is proportional to the area of rubber in contact with the road. The argument from contact area, however, is not adequate to explain the differences between old or smooth tread tires and new tread. On a wet surface the smooth tread will have a smaller coefficient than the new tread at higher speeds (e.g., above 30 mph), although the former has greater contact area. This may be explained by the fact that the new tread tire squeezes the water into the grooves or out to the side; whereas the old tread retains the water in a pocket, thus preventing intimate contact. At low speeds, however, it has been found that the coefficient may be greater for smooth tread than for new tread, probably because the low speeds permitted a "squeezing" effect. This effect can be seen in Table 13.<sup>7</sup>

**TABLE 13. Coefficients of Friction — Concrete Road**

NEW TIRES			
Road Wet		Road Dry	
<i>Speed mph</i>	<i>Coef</i>	<i>Speed mph</i>	<i>Coef</i>
6.0	0.55	5.4	0.82
10.5	0.51	11.0	0.75
16.0	0.45	15.25	0.69
20.0	0.41	21.0	0.62
26.25	0.38	25.5	0.58
OLD TIRES			
4.8	0.65	5.0	0.74
9.7	0.61	10.3	0.65
15.1	0.50	14.8	0.59
20.0	0.43	21.0	0.52
24.6	0.37	25.6	0.48

Reprinted by permission from: R. A. Martin, "Minimum Stopping Distances of Automobiles," *Proc. Indiana Ac. Sci.*, 47, 199-203 (1937).

Experiments recently conducted with tires on extremely clean glass indicate that under certain ideal conditions the coefficient of friction may have a value greater than one.<sup>8</sup> It was found that smooth tires on clean glass developed much more friction than treaded ones and that in both cases the coefficient exceeded the value of unity.



### Condition of the Road Surface<sup>9, 10</sup>

The weather conditions are extremely important. Although the coefficient of friction of the average paved roadway is usually between 0.6 and 0.8 in dry weather, this value may be lowered considerably by rain, snow, ice, or mud. The coefficient of friction for a wet road is about 0.5; for packed snow or mud it is about 0.2; for ice the value is about 0.1; for very wet, muddy, or icy roads the value is sometimes less than 0.1. The coefficient for snowy and icy roads depends, too, upon the temperature. When the temperature is near 32 F the pressure of the wheels on the snow or ice melts the surface to a liquid state, thus lowering the coefficient. If, however, the temperature is well below freezing, this melting does not take place to any great extent, and considerable frictional resistance may be offered by the road. The coefficient for snow may then range from 0.3 to 0.5; for ice, 0.2 to 0.5.

The presence of dirt, sand, mud, or other foreign substance on a concrete or asphalt road at normal temperatures lowers the available coefficient of friction,

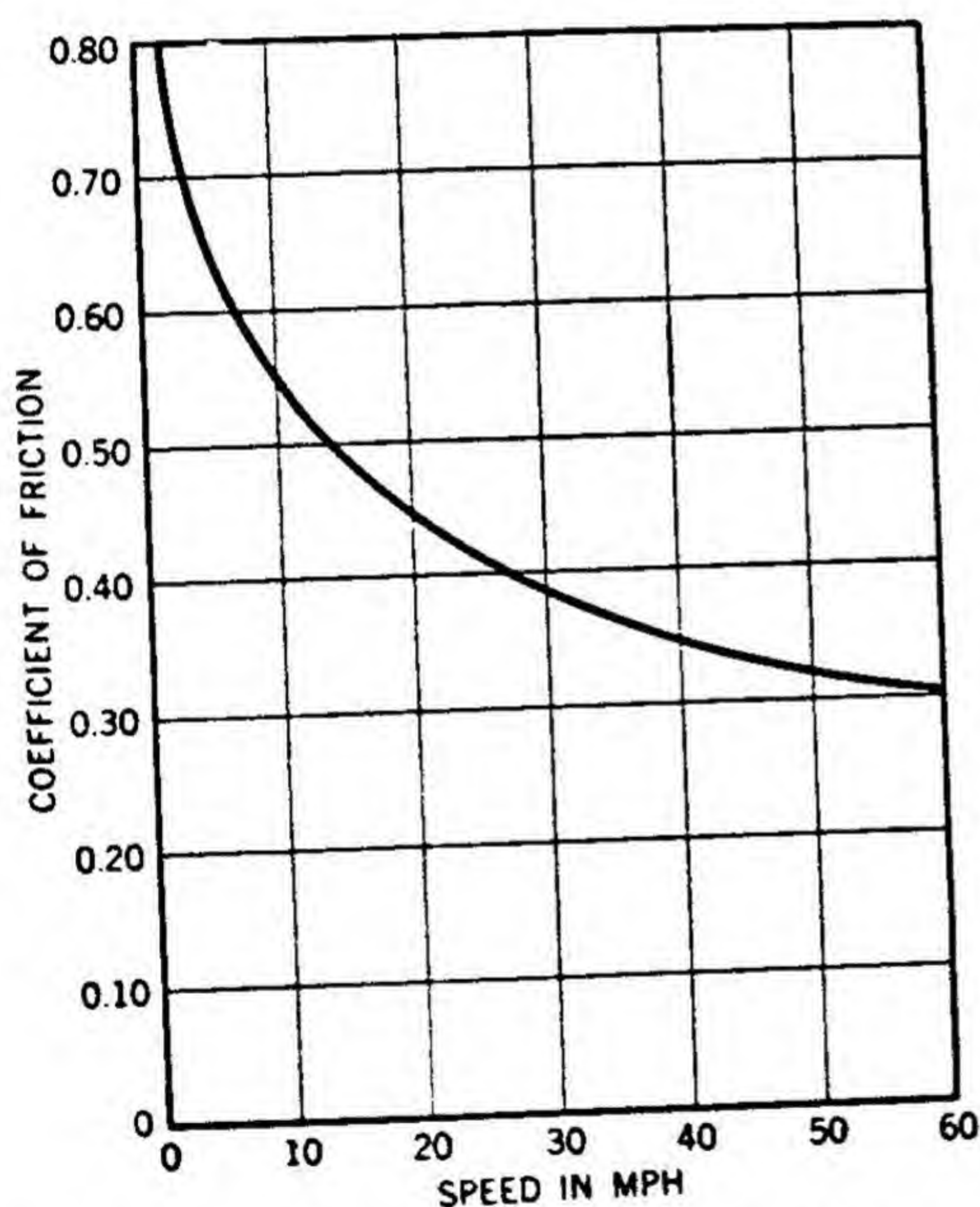


Fig. 186. Variation of coefficient of friction with speed on a wet roadway.

the decrease in  $\mu$  depending upon the nature and quantity of the foreign material present. This lowering effect is present on both wet and dry surfaces. For example, mud on concrete was found to have a coefficient of 0.2; with sand or cinders on concrete, the coefficient varied from 0.4 to 0.6.

### Effect of Speed<sup>11, 12</sup>

On dry surfaces there is a decrease in the coefficient of friction with increased speed. Figure 188 is a typical curve illustrating this variation. The curve, of course, will vary for different tires and different roads. On some roads, for example, the coefficient may vary from 0.8 at 40 mph to 0.7 at 60 mph. This decrease is due to the fact that more work is done in stopping

a vehicle at higher speeds. The tires are dragged along the surface a greater distance and the heat developed softens the rubber, thus decreasing the traction.

On wet surfaces, according to Moyer, the coefficient decreases with increased speed (Fig. 186). The decrease, however, is greater than that for dry surfaces. A contrary effect is found on snow and gravel. On these surfaces the coefficient of friction increases slightly with speed. This phenomenon may be due to the fact that at low speeds the particles comprising loose surfaces are more easily displaced and tend to decrease the traction.



### Effect of Temperature

Coefficient of friction increases as the temperature decreases. A drop of 50 F in temperature may increase the coefficient of friction on wet concrete by 0.1. The decrease in frictional resistance with increasing temperature is caused by the heating of the tires and its effect on the rubber.

### Effect of Skid Chains

The use of skid chains provides a greater coefficient of friction on surfaces such as ice or snow. The coefficient increases with increasing speed. Some chains are more effective than others. Two- and four-link chains are about equally effective in straight skidding. Two-link chains, however, are more effective than the four-link type in side skids. Claw chains are also superior in this respect to standard chains.

## 3. SKIDMARKS

When the brakes of a moving car are forcefully applied, the friction between tire and roadway heats the rubber, depositing a thin layer in the path of the tires. Sometimes a black mark is formed by displaced surface materials — dust, tar, etc. Some synthetic tires of high heat resistance exert a cleaning action on the road surface. These lines are called *skidmarks*. In a motor vehicle accident the problem which confronts the investigator is the determination of deficiencies in the brakes or of negligence\* on the part of the driver due to excessive speed. Usually the only evidence present is a set of skidmarks. These marks may be shown to be a measure of the probable stopping distance.

There is a considerable technique in measuring and observing skidmarks, which can be learned only by experience. It is highly important, for example, to be able to distinguish between skidmarks and tire tread prints which on some types of surfaces, particularly wet ones, is quite difficult. In measuring skidmarks several precautions should be observed in order to favor the defendant in the calculations. Since the length of the skidmark varies as the square of the velocity, any reasonable doubts concerning the length of the accident skidmarks should be resolved in favor of the shorter value, which would lead to a lower initial speed. A series of measurements of each of the four skidmarks should be made and the arithmetical average computed. If there are only three skidmarks, the sum of the three lengths should be divided by four, although it is possible that some braking force was contributed by the wheel which left no skidmark.

In some cases it will be found that the skidmarks are not continuous. This may be due to an interruption in the application of the brakes or because of bouncing of the wheels. In these cases the gaps should not be included in the measurement of the lengths of the skidmarks.

It is necessary in some tests, which will be described later, to produce skid-

\* The term *negligence* is used loosely throughout this discussion. Speeding alone is, in general, not considered by the courts to constitute *culpable negligence* or *recklessness*.



marks with the suspected car or a test car. In these tests it is important to determine the point on the road at which the brakes were applied. This may be done by signal from the driver to an observer. Another method involves the use of a pistol\* which is attached to the front bumper of the car, pointing down. At the moment of full application of the brakes an electrical circuit is activated and the pistol projects a blob of pigment to the ground.

The National Safety Council recommends the following procedure in measuring skidmarks:

"The length of each skidmark should be measured carefully and the distance recorded. Skidmarks laid down by a front wheel should be measured from the beginning of the skidmark to the final position of the front wheel, unless there is a gap or break in the skidmark. Similarly, skidmarks laid down by rear wheels should be measured from the beginning of the skidmark to the rear wheel.

"Sometimes, the skidmarks for the rear wheels directly overlap those laid down by the front wheels, and it is difficult to identify the point at which the front wheels began to skid. Very careful examination of the point will usually reveal a beginning point for the front wheel skidmarks. Generally, the vehicle does not go in exactly a straight line, and one skidmark will be slightly to one side or the other at some point along the line.

"When identifying the beginning point of a skidmark, it should be remembered that when the wheel first starts to skid, it often does not leave a heavy skidmark. If the person will sight along the skidmark with his eye close to the pavement, he will often be able to identify a lighter skidmark extending several feet in advance of the beginning of the very heavy skidmark. This lighter skidmark can be used as a part of the skidmark length."<sup>13†</sup>

It will be found that some authorities differ in their recommendations for the measurement of skidmarks. The reader should consult the references for an appreciation of their opinions.<sup>14, 15, 16</sup>

#### 4. STOPPING DISTANCE ON LEVEL GROUND

We investigate, now, the problem of determining the minimum distance in which a car can be brought to a halt on a level stretch of road. The term *stopping distance*‡ or *braking distance* is used to mean the distance traveled by the vehicle from the moment of full application of the brakes to the moment at which the car was brought to rest.

If  $m$  is the mass of the car;  $v$ , the speed when the brakes are applied;  $g$ , the acceleration due to gravity;  $\mu$ , the coefficient of friction between the tires and the road; and  $s$ , the distance in which the car is brought to a stop after the brakes

\* Information concerning stopping distance pistols and their use can be obtained from the National Safety Council, Chicago, Illinois.

† "Use of Skidmarks in Calculating Motor Vehicle Speeds," National Safety Council, Public Safety Memo. No. 28, Chicago, 1940, p. 14.

‡ Some authorities distinguish between these two terms. Stopping distance is taken to include the distance traveled during the driver's reaction time plus the braking distance as defined here. This distinction, however, is not important in the present discussion.



are applied; we can determine  $s$  by equating the kinetic energy of the moving car to the work done in bringing the car to a stop. Thus:

$$\frac{1}{2}mv^2 = mg\mu s,$$

or

$$s = \frac{v^2}{2g\mu} \quad (2)$$

The kinetic energy of the wheels does not enter, since true skidmarks are made only after the wheels are locked. Engine resistance and air resistance can also be ignored. The magnitude of these latter forces and their variation with speed has been investigated by Martin.<sup>17</sup>

If the car is going 40 miles an hour when the brakes are applied and the coefficient of friction is taken as 0.80, we have

$$v = 40 \text{ mph} = 59 \text{ fps};$$

$$g = 32 \text{ fps per sec}; \mu = 0.80;$$

and

$$s = \frac{(59)^2}{2 \times 32 \times 0.80} = 68 \text{ ft.}$$

We may simplify equation (2) by using the proper factors to convert fps to mph. The equation is then

$$s = \frac{v^2}{30\mu}, \quad (2')$$

where  $s$  is in feet and  $v$  is in mph.

Studying this equation, we see that  $s$  varies as  $v^2$ ; i.e., stopping distance varies as the square of the velocity. A car going 40 mph will require four times the stopping distance of a car going 20 mph. At 80 mph, sixteen times the stopping distance of 20 mph is required.

Further,  $s$  is inversely proportional to  $\mu$ , the coefficient of friction. The value of  $\mu$  used in our example is an optimum value, and it has been assumed that the car is sliding with all four wheels locked; hence our stopping distance is a true minimum and by no means provides a margin of safety.

It should be noticed that  $m$  does not appear in equation (2). In other words, stopping distance is independent of the mass of the car in question (except in so far as  $\mu$  is affected). We conclude from this that a heavy car and a light car will, after full application of the brakes, travel the same distance before stopping except for the slight variation due to a change in frictional resistance, which has been previously explained.

Overloading of a truck, however, may place an excessive load on the brakes. The kinetic energy of the truck is equal to  $\frac{1}{2}mv^2$ . This energy will in braking be converted mainly into heat. If the mass of the truck and load is doubled, the brakes must do twice the work; if the speed of the truck is doubled, the brakes must do quadruple the work. If both speed and mass are doubled, the brakes must do eight times the work. Thus, the safety limits of the brakes may be overreached and a failure in braking may result.



These latter remarks are in no way contradictory of the previous conclusion that stopping distance is approximately independent of the weight of the vehicle. Braking efficiency reaches a maximum when the wheels slide and do not rotate. The condition is achieved independently of the mass of the truck.

Equation (2) will be used hereafter to determine the original speed of a car by measuring stopping distance. In this form the equation becomes

$$v = \sqrt{30\mu s}. \quad (3)$$

## 5. STOPPING DISTANCE ON HILLS <sup>18, 19, 20</sup>

Thus far we have assumed that the surface on which the stop was made is level ground. Equation (2) was derived with this assumption. If, however, the stop was made on an incline, we must account for the energy concerned in descending or ascending as the case may be.

Figure 187 is a diagram of a car of weight  $W$  on an inclined plane making an angle  $\alpha$  with the horizontal. What is the work done in bringing the car to a stop in a distance  $AC$ ?

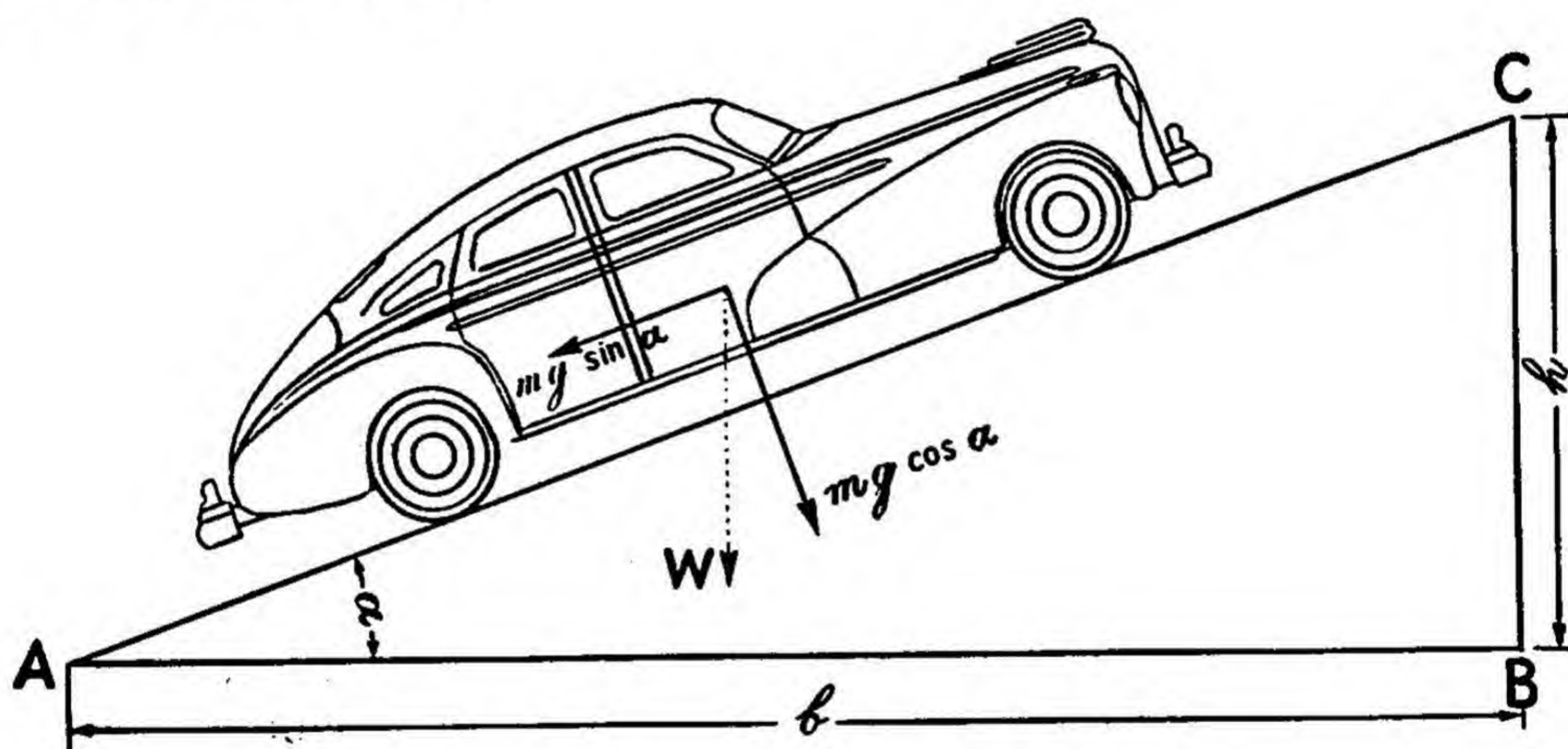


Fig. 187. Forces acting on a car on an inclined plane.

If we resolve the weight into its components parallel and normal to the plane, we find that these are respectively  $mg \sin \alpha$  and  $mg \cos \alpha$ . Since there is friction between the tires and the road, a frictional force of  $\mu mg \cos \alpha$  opposes motion in either direction. To drive the car up the plane a distance  $AC = L$ , a force equal to  $mg(\mu \cos \alpha + \sin \alpha)$  must be applied. Equating the work done to the energy of the car we have:

$$\frac{1}{2}mv^2 = mgL(\mu \cos \alpha + \sin \alpha),$$

or

$$v^2 = 2gL(\mu \cos \alpha + \sin \alpha). \quad (4)$$

Since  $\cos \alpha = \frac{b}{L}$  and  $\sin \alpha = \frac{h}{L}$ ,

$$v^2 = 2g(\mu b + h)$$



or

$$v = \sqrt{2g(\mu b + h)}.$$

Expressing  $v$  in mph we have

$$v = \sqrt{30(\mu b + h)}. \quad (5)$$

From the energy equation we can see that the work done by the car in coming to rest is simply the sum of the work done against frictional forces along the horizontal  $b$  and the work done in lifting the car a distance  $h$  vertically.

If the car had been going down the hill, the sign of  $h$  or  $\sin \alpha$  would be negative since the weight of the car no longer opposes the motion. Obviously, if part of the skidmark is made at the bottom of the hill this distance must be added as another term in equation (4); thus

$$v = \sqrt{2gL(\mu \cos \alpha + \sin \alpha) + \mu s}$$

or, in mph,

$$v = \sqrt{30L(\mu \cos \alpha + \sin \alpha) + \mu s},$$

where  $s$  is the length of the skid on level ground.

It is probable that equation (4) will be more convenient to use. The gradient,  $\tan \alpha$ , can usually be found in the official records or determined at the scene with the proper instruments.<sup>21</sup> The length of the skidmark will of course be  $L$ . A good approximation to equation (5) is given by

$$v = \sqrt{30L \left( \mu + \frac{p}{100} \right)}, \quad (6)$$

where  $p$  is the grade of the hill expressed in per cent. The assumption made in this formula is that  $L$  is approximately equal to  $b$ . For descending grades we have

$$v = \sqrt{30L \left( \mu - \frac{p}{100} \right)}. \quad (6')$$

## 6. THE DECELEROMETER

Although the decelerometer is described here at some length, it is not necessary in determining the initial speed of a car. Skidmarks alone will provide the necessary information. The convenience offered by this instrument, however, has resulted in its extensive use in some localities. Some authorities do not consider it a reliable measuring device for the purposes with which we are concerned here. Errors can arise in the use of this instrument from various sources, e.g., weight transfer and sudden stopping. For the sake of completeness, however, the instrument is treated here.

### Mechanism

The decelerometer is a brake-testing instrument which measures deceleration. One type will be described here. The principle governing this instrument is Newton's first law of motion: A body persists in its state of rest or uniform motion in a straight line with constant speed unless it is compelled by a force



to change that state. The essential part of the decelerometer is a freely swinging pendulum suspended within a protecting case. The instrument is attached to the car. When the brakes are applied to the moving car, the pendulum continues its forward motion and is raised to an angle which is determined by the original speed of the car. The position of the pendulum is recorded on dials turned by an auxiliary mechanism which is governed by the motion of the pendulum. This auxiliary mechanism is an armature. The pendulum is made of a magnetic metal; hence its motion will cause the armature to follow.

If the decelerometer is operated on level ground the initial position of the pendulum is exactly vertical. If, however, the car is being tested on a hill, an adjustment can be made to compensate for the fact that the pendulum is not at right angles to the road surface. Obviously, this adjustment can also be used to determine the gradient of the hill.

### Readings and Interpretations

Two readings are given by the decelerometer: one is the number of feet in which the car stopped after the application of brakes; the other is the braking efficiency. The instrument is, however, calibrated for a speed of 20 mph. Thus, the instrument records the number of feet in which the car would have stopped had the car been traveling at a rate of 20 mph. This does not mean that it is necessary to operate the car at 20 mph in order to obtain correct readings on the decelerometer. For example, assume that the car is run at 30 mph when the brakes are applied. The decelerometer may give a reading of 25 feet, whereas the actual stopping distance is  $56\frac{1}{4}$  feet. This reading means that the car would have required 25 feet in which to stop had the speed been 20 mph.

This stopping distance is interpreted in terms of braking efficiency on the other dial. The braking efficiency is expressed as a percentage of the legal requirements for stopping distance. Typical legal requirements on dry level pavement for 20 mph would be the following:

Four-wheel brakes . . . . .	30 ft
Two-wheel brakes . . . . .	45 ft
Hand brake . . . . .	75 ft

With perfect four-wheel braking at 20 mph and a coefficient of friction of 1, we should have from equation (2') a stopping distance of

$$s = \frac{(20)^2}{30 \times 1} = 13.3 \text{ ft.}$$

Naturally this stopping distance is far too severe. Allowing for personal reaction and other variables a distance of 30 ft was arrived at for dry, level pavement. Now, 13.3 is 44.4 per cent of 30; hence 44.4 brake percentage would be the legal requirement for four-wheel brakes. We may substitute this value in place of the coefficient of friction to determine legal stopping distances. For example, if a car is traveling at 30 mph, the stopping distance should be

$$s = \frac{(30)^2}{30 \times 0.444} = 68 \text{ ft.}$$



### Determination of Coefficient of Friction by Means of Decelerometer

As an alternative to the dynamometer and other methods, the decelerometer is sometimes used to measure coefficients of friction. The results are subject to the errors already mentioned. Using equation (1) we have

$$\mu = \frac{v^2}{30x}$$

The car is operated at a definite speed, say 25 mph, the stopping distance is read from the decelerometer. Let us say that this reading is  $x$  ft. We have then

$$\mu = \frac{(20)^2}{30x}$$

(The value of 20 is used for  $v$  instead of 25 because of the manner in which the decelerometer records stopping distances as explained above. Had we used  $v = 25$ , then we should have had to transform  $x$  ft into a stopping distance  $x_1$  for 25 mph by the equation

$$x_1 = \frac{(25)^2}{(20)^2} x = 1.56x$$

and

$$\mu = \frac{(25)^2}{30 \times 1.56x}$$

In any case, the value obtained for  $\mu$  is the same.)

## 7. DETERMINING THE INITIAL SPEED FROM SKIDMARKS

One of the purposes of an investigation of an automobile accident is to determine the existence or absence of negligence. This negligence may lie in excessive speed, faulty brakes, or failure to apply the brakes in time. We are concerned with the first two causes since the last cannot be determined by the physical principles which have been discussed so far.

For this purpose we may classify motor vehicle accidents as collisions between a vehicle and a person, and collisions between two vehicles. The distinction is practical. In the first case the collision does not affect the stopping distance because the mass of the person is negligible in comparison with the mass of the car; hence the skidmark is a true measure of the stopping distance, and may be used to calculate the velocity at which the car was traveling. The second case, however, presents other possibilities which will be treated later.

### Collision Between Vehicle and Person

#### SUSPECTED VEHICLE OPERABLE

If the vehicle involved in the accident can still be operated, the following tests can be conducted to determine the initial speed of the vehicle:

(a) Drive the suspected car at 30 mph and apply the brakes fully. Measure the skidmarks. Repeat the test until four sets of values are recorded. Calculate



the mean value. If  $v_1$ ,  $s_1$  refer to the initial speed and skidmarks of the accident, and  $v_2$ ,  $s_2$  refer to the values determined by the tests, we have

$$v_1 = \sqrt{30\mu s_1}$$

$$v_2 = \sqrt{30\mu s_2}$$

Hence, by dividing,

$$v_1 = v_2 \sqrt{\frac{s_1}{s_2}} \quad (7)$$

Check the speedometer of the suspected car against an officially tested speedometer in another car.

**EXAMPLE.** The average length of the skidmarks found at the scene of a motor vehicle accident is 60 ft. By running the car at a speed of 30 mph and applying the brakes fully (four-wheel brakes) it is found that the average braking distance is 44 ft. Determine from the data the initial speed of the car in producing the 60 ft skidmarks.

$$s_1 = 60 \text{ ft; } s_2 = 44 \text{ ft; and}$$

$$v_2 = 30 \text{ mph.}$$

Hence from equation (6)

$$v_1 = 30 \sqrt{\frac{60}{44}}$$

or

$$v_1 = 35 \text{ mph.}$$

(b) The initial velocity can also be determined from the original skidmarks alone. In this case the coefficient of friction must be determined. This can be done by any of the methods described above. Equation (3) is used, viz.,

$$v = \sqrt{30\mu s}.$$

This test is equivalent to (a); in fact, depending upon the method used for determining  $\mu$ , it may be the same as test (a).

**EXAMPLE.** If the average length of a skidmark is 64 ft on a roadway of which the coefficient of friction for rubber is found to be 0.82, what was the initial speed of the car?

$$\mu = 0.82; s = 64 \text{ ft.}$$

Hence

$$v = \sqrt{30 \times 0.82 \times 64}$$

or

$$v = 40 \text{ mph.}$$

(c) Test (a) can be performed using the decelerometer to measure the second skidmark or stopping distance.

**EXAMPLE.** The average length of the skidmarks at the scene of an accident is found to be 60 ft. Operating the suspected car with a decelerometer and applying the brakes, a stopping distance of 15 ft is recorded on the decelerometer. At what speed was the car traveling when the skidmarks of the accident were made? We have:

$$s_1 = 60 \text{ ft;}$$

$$s_2 = 15 \text{ ft;}$$

$$v_2 = 20 \text{ mph;}$$

$$v_1 = ?$$



( $v_2$  is taken as 20 because, as previously explained, the decelerometer is adjusted to record the distance in which the car would have stopped had the speed been 20 mph).

From equation (7)

$$v_1 = 20 \sqrt{\frac{60}{15}} = 40 \text{ mph.}$$

(d) Test the brakes of the car by means of the decelerometer. Record the percentage of braking efficiency; i.e., record the other readings of test (c) with the decelerometer.

*Summary:* Test (a) is the fundamental test. Tests (b) and (c) are equivalent to test (a). Test (d) distinguishes the case of defective brakes. It should be noted that nothing need be known of the coefficient of friction to determine the initial speed;  $\mu$  may be looked upon as a proportionality constant which is eliminated from the two simultaneous equations leading to equation (7). In practice, test (b) may be omitted. Test (a) is sufficient. If a decelerometer is available, tests (c) and (d) may be applied. Because of the decrease of  $\mu$  with increasing speed, cars should be tested at a speed of at least 30 mph, the speed at which  $\mu$  begins to attain a constant value. This precaution is taken for the protection of the defendant.

### SUSPECTED VEHICLE INOPERABLE

The following tests are similar to the preceding ones except for the fact that a second or *standard* car is used instead of the accident car. This second car should have a tested speedometer. If possible the tires should be removed from the accident car and placed on the standard car during the test.

(a) This test is the same as test (a) above except that the comparison skidmark is produced by means of another car. This car is operated at a speed  $v_2$ ; the brakes are fully applied and the skidmark,  $s_2$ , is measured. Equation (7) is then applied. The use of the second car is a valid procedure because the stopping distance will be very nearly the same for both cars if the wheels are fully locked at any speed.

(b) Same as test (b) above.

(c) Same as test (c) above, but using the standard car with the decelerometer.

*Summary:* Again, test (a) is fundamental. Test (b) may be ignored. Test (c) may be applied where a decelerometer is available. These tests tell us nothing of the braking efficiency of the suspected car. It should be remembered that it is possible to have a "legal" skidmark and still have criminal negligence which cannot, however, be proved.

### Measurements and Sources of Error

By the methods of Chapter 5 (see p. 51) the following relations can be derived:

$$R_r = \pm \frac{v}{2} \sqrt{\frac{r_\mu^2}{\mu^2} + \frac{r_s^2}{s^2}} \quad (8)$$



and

$$R_{v_1} = \pm v_1 \sqrt{\frac{r_{v_2}^2}{v_2^2} + \frac{r_{s_1}^2}{4s_1^2} + \frac{r_{s_2}^2}{4s_2^2}} \quad (9)$$

Equation (8) gives us the probable error  $R_v$  in computing  $v$ , which is the result of probable errors  $r_\mu$  in  $\mu$  and  $r_s$  in  $s$ , when the relation

$$v = \sqrt{30\mu s}$$

is used.

Equation (9) gives the probable error  $R_{v_1}$  in computing  $v_1$ , which is the result of probable errors  $r_{v_2}$  in measuring  $v_2$ ;  $r_{s_1}$  in  $s_1$ ; and  $r_{s_2}$  in  $s_2$ ; when the relation

$$v_1 = v_2 \sqrt{\frac{s_1}{s_2}}$$

is used.

These relations should be used to guide the investigator in evaluating his results.

### SKIDMARKS

It has been assumed in the previous treatment that the skidmark is an adequate measure of the stopping distance. This is not, however, strictly true. The full stopping distance is the *braking distance* which is the length of the skidmark plus the distance which the car traveled after application of the brakes. Thus, the skidmark is not sufficiently long to measure correctly the braking distance. The error, however, will occur in two places: (a) in measuring the skidmark at the scene of the accident, where a short length will favor the defendant; and (b) in measuring a test skidmark where a short length will be adverse to the defendant. From equation (7) we see that these errors are, to some extent, compensating. Nevertheless, in order to insure fair treatment for the defendant the investigator should not restrict himself to measuring merely the test skidmark. He should measure the full braking distance. Thus, by using the longer measure in equation (7), a true minimum speed can be established.

Various authorities distinguish these two measurements by the terms *minimum* speed and *probable* speed. *Minimum* speed refers to the value for the speed obtained by substituting in equation (7) the value for the test *braking distance*. *Probable* speed is determined by substituting simply the length of the test *skidmark*.

The probable speed takes into account the deceleration which is caused by air and engine resistance, additional braking action before the wheels are locked, and braking action from wheels which do not produce a skidmark. It will be noted that these factors also exist in measuring the accident skidmark but are ignored. Hence the ignoration of these factors in that measurement would compensate, if we chose to neglect them in the measurement of the test skidmark. Thus it may seem that the defendant is unduly favored by using braking distance instead of skidmark length in the test measurement. In view, however, of the number of variables which enter into the computations this conservatism is well justified.



A steel tape, 100 ft in length, should be used in measuring the length of a skidmark. Two men are required to make the measurement. If the measurement is greater than the length of the tape, care should be taken to measure in as straight a line as possible. A piece of chalk should be used to mark the point where the tape ends the first time and the point at the end of the skidmark. The sources of error usually lie in manipulation: not having the tape horizontal, failure to stretch the tape tight, sag, pull, and marking of the tape lengths. When a normal amount of care is taken, these errors are usually quite small in comparison with the error due to the approximations that are implicit in the formulas. The largest error is usually that caused by inaccurate estimates of the starting point and end point of the skidmark.

### MEASURING THE TEST SPEED

In equation (9) we see that the error in the test speed  $v_2$  is quite important. A larger value of  $v_2$  results in an increase of  $v_1$ . Hence the speedometer of the test car should be carefully tested against a standardized speedometer at the speed at which the tests are to be run. In the test run the speedometer should be allowed to hold its point for a short time before the brakes are applied.

### COEFFICIENT OF FRICTION

One of the assumptions that have been made in deriving the working equations is that deceleration is constant. This is only approximately true. The coeffi-

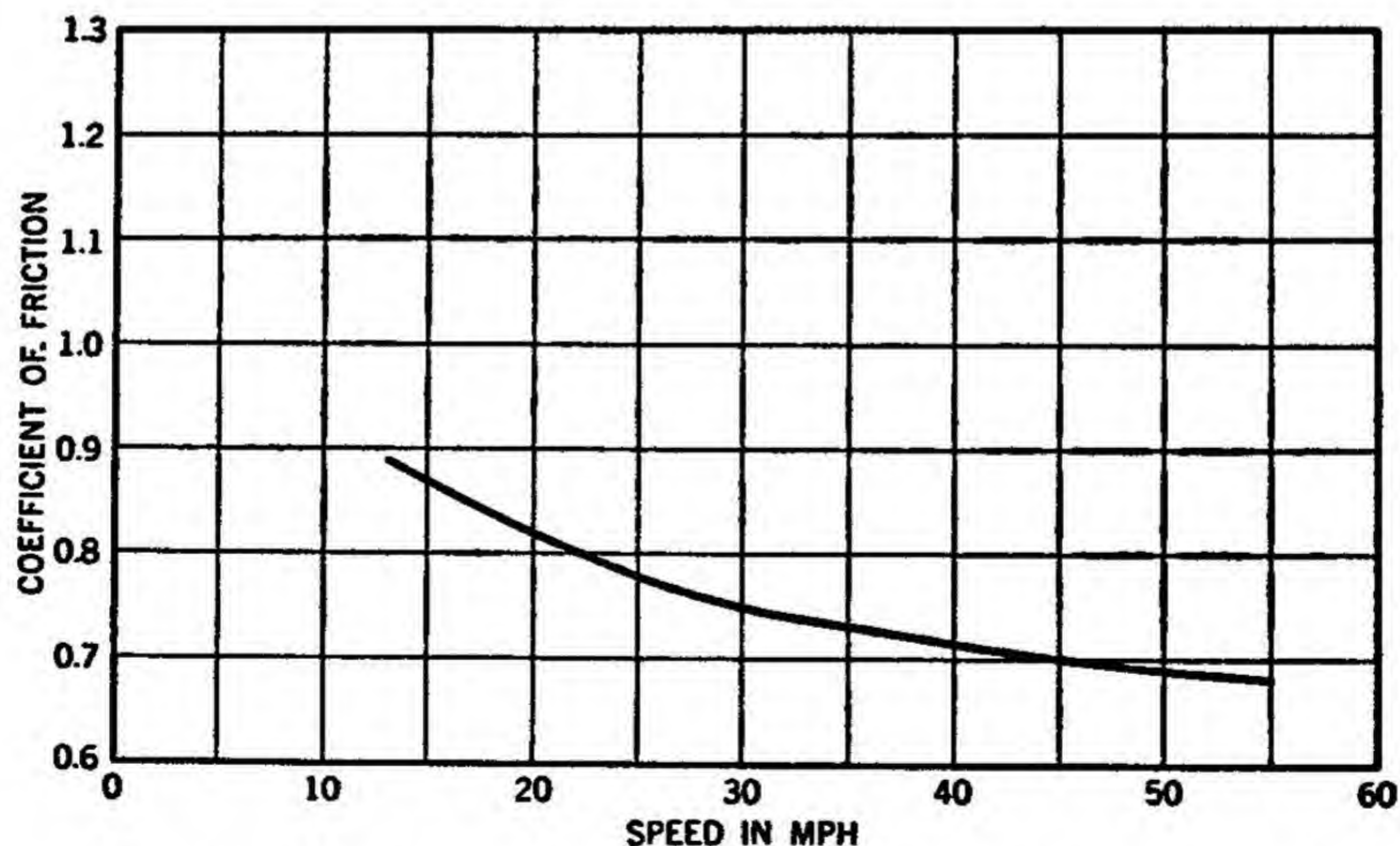


Fig. 188. Relation between coefficient of friction and speed.

cient of friction decreases with increasing speed. The effect of the error may now be seen from equation (8). If the test skidmark is made from a speed of 20 mph, the coefficient of friction which is being used is probably too great. From Fig. 188 we see that the coefficient is 0.82 at 20 mph and 0.72 at 40 mph. If the accident car had been traveling at about 40 mph, the error  $r$  in using 0.82 as the coeffi-



cient of friction would be 0.10. If we set  $r_s = 0$ , then the error (which is now a correction, since we know its direction) in  $v$  will be

$$R_v = \frac{40}{2} \times \frac{0.10}{0.72} = 2.8.$$

Thus, at 40 mph this would add 2.8 mph to the speed computed from equation (8).

The error caused by using too great a value for  $\mu$  occurs not only in using equation (3) but also in equation (7), even though  $\mu$  does not explicitly enter into that relation. This may be seen from the fact that  $\mu$  was assumed constant in deriving the latter equation. The error enters wherever the test skid is made at a lower speed than the accident speed.

One way of avoiding this error is to reproduce approximately the length of the accident skid in making the test skid. To do this the test is first run at 30 mph and the accident speed is approximately determined from equation (7). The test is then repeated at this approximate speed and equation (7) is again applied for a better approximation.

Another method of compensating for the error is to employ a curve such as that in Fig. 188 to determine the error involved in using too small a value for  $\mu$ . Thus if  $\mu_2$  is the value obtained from the curve for the test speed and computations lead to an accident speed of  $v_1$  for which the tabulated coefficient is  $\mu_1$ , the relative error in  $v_1$  due to the error in  $\mu$  is, from equation (8), (neglecting  $r_s$ ),

$$\frac{R_{v_1}}{v_1} = \frac{r_\mu}{2\mu}.$$

Our error now is in reality a correction. We have assumed the plus sign since we know the direction of the error or correction. We may now write  $\Delta v_1$  for  $R_{v_1}$  and  $(\mu_2 - \mu_1)$  for  $r_\mu$  to represent these corrections. Thus

$$\frac{\Delta v_1}{v_1} = \frac{\mu_2 - \mu_1}{2\mu_1}$$

If  $v_1^*$  represents the speed  $v_1$  corrected for the variation caused by a variable  $\mu$ , we have

$$v_1^* = v_1 - \Delta v_1 = v_1 \left( 1 - \frac{\mu_2 - \mu_1}{2\mu_1} \right)$$

or

$$v_1^* = \frac{v_1}{2} \left( 3 - \frac{\mu_2}{\mu_1} \right). \quad (10)$$

**EXAMPLE.** In a test skid at 30 mph the braking distance is found to be 40 ft. The length of the accident skidmark is 120 ft. Compute the accident speed adjusting for the variation in the coefficient of friction. (Assume that the values in Fig. 188 are valid for the road in question.)

Since  $v_2 = 30$  mph,  $s_2 = 40$  ft, and  $s_1 = 120$  ft, we have from equation (7)

$$v_1 = \sqrt{\frac{(30)^2 \times 120}{40}}$$



or

$$v_1 = 52 \text{ mph.}$$

From Fig. 188 we see that, at 30 mph,  $\mu_1 = 0.75$  and, at 52 mph,  $\mu_1 = 0.69$ . From equation (10)

$$v_1^* = \frac{52}{2} \left( 3 - \frac{0.75}{0.69} \right)$$

or

$$v_1^* = 49 \text{ mph.}$$

A truer value for  $\mu$  would be the mean value between the two speeds. The above method, however, has the advantage of simplicity and, in addition, is a more conservative value.

In order to apply this correction it is necessary to have a table of values for coefficient of friction at various speeds for a given road. Such a table can be readily made for the roads of a given locality. Tables are also available in the literature.

The error caused by the variation of the coefficient of friction with the speed of the car can be corrected for also by employing a relation other than equation (1). In the latter equation the coefficient varies as  $v^2$ . Other investigators have found that the facts are more nearly in agreement with a relation in which the coefficient varies as  $v^{2.075}$  on dry surfaces,<sup>22, 23</sup> and as  $v^{2.33}$  on wet surfaces.<sup>24</sup>

Thus in place of equation (7) the following relations may be used for dry and wet surfaces respectively:

$$v_1 = v_2 \left( \frac{s_1}{s_2} \right)^{\frac{1}{2.075}}$$

and

$$v_1 = v_2 \left( \frac{s_1}{s_2} \right)^{\frac{1}{2.33}}$$

Again, it should be noted that whether the correction is made by means of equation (10) or by means of these last equations, the same operation is being performed and the same variable corrected for.

### Collision of Two Vehicles<sup>25, 26</sup>

In the collision of a vehicle and a person the physical laws governing the impact of two bodies were ignored because of the disparity in the weights of the bodies. When, however, two vehicles of comparable weights collide, these laws must be applied in the analysis of the evidence of subsequent motion to determine original velocities. The problem is not a simple one, and in general, the investigator will come to no satisfactory conclusion. For the sake of the special cases wherein a solution is possible, a general treatment of the subject is given here.

The approach to the problem is the same as that used previously; namely, the kinetic energy of the vehicle in question is equated to the work done by the vehicle in coming to a stop. Thus

$$\frac{1}{2}mv^2 = E,$$



where  $E$  is the total energy consumed in stopping. The energy  $E$  has been absorbed in various ways, among which are

- $e_1$  = work done in skidding before and after collision
- $e_2$  = work done in braking without skidding
- $e_3$  = loss of energy in impact
- $e_4$  = work done in moving the other vehicle

There are other possible ways in which energy can be absorbed — for example, coming to rest without braking after collision. It should be remembered, however, that any errors incurred by ignoring further ways in which energy is absorbed will favor the defendant. The investigator is concerned with establishing a reasonable lower limit to the speed of the car.

Having computed  $e_1, e_2, \dots, e_n$ , we have

$$E = \sum_{i=1}^n e_i$$

or

$$E = e_1 + e_2 + \dots + e_n \quad (11)$$

and

$$v = \sqrt{\frac{2E}{m}} \quad (12)$$

The difficulties involved in computing the work done in these various ways must now be considered.

(a)  $e_1$  — The energy absorbed in skidding is calculated by means of the skid-mark measurements as explained previously.

(b)  $e_2$  — The work done in braking without skidding presents a difficulty, since the distance through which the vehicle traveled under this condition cannot be readily fixed. Sometimes, however, the driver readily admits to applying the brakes at a certain point. The distance from this point to the beginning of the skidmarks can then be measured. The braking force of the wheels can also be measured by a brake-testing machine, but such a test cannot measure accurately the pre-skid braking pressure. Knowing the coefficient of friction of the road, the work done can then be calculated as the product of the braking force, the coefficient of friction, and the distance traveled. Because of the difficulties involved in determining accurately the braking force and the point at which the brakes were applied, it is a safer procedure to ignore  $e_2$  and establish the result from the other data as has been done previously.

(c)  $e_3$  — On impact the energy is dissipated mainly in heat and the deformation of the vehicles (the deformation energy is also heat energy unless the center of gravity is shifted). If the vehicles were to collide bumper to bumper at moderate speeds, it would be possible to apply the laws of impact for elastic bodies (assuming a coefficient of restitution were established). The kinetic energy loss in impact can be computed by analyzing the kinetic energy of the two cars relative to their common center of gravity and applying Newton's law of impact. The loss of energy can be shown to be equal to

$$\frac{\frac{1}{2}m_1m_2(1 - \epsilon^2)(v_1 - v_2)^2}{m_1 + m_2}, \quad (13)$$



where  $m_1, m_2$  are the masses of the vehicles;  $e$  is the coefficient of restitution; and  $v_1, v_2$  are the speeds of the vehicles before impact. This equation introduces the speed of the second car and also the coefficient of restitution as quantities to be determined. In the face of these obstacles, the problem becomes quite difficult. In general, however, laws assuming that the bodies are fairly elastic are inapplicable because of the great damage which usually results from a collision.

(d)  $e_4$  — The energy absorbed in moving the other vehicle (vehicle no. 2) is relatively simple to calculate when the vehicle does not roll on its wheels but is moved sideways or with locked wheels. The work done in moving a car of weight  $W_2$  through a distance  $s$  along a surface of frictional coefficient  $\mu$  is then given by

$$e_4 = \mu W_2 s \quad (14)$$

( $\mu$  here is the coefficient of friction for side skidding, which may differ from that for straight skidding).

**EXAMPLE.** One vehicle collides with a second vehicle and pushes it to the side a distance of 30 ft. If the second vehicle weighs 3000 lb and the coefficient of friction of the roadway is found to be 0.80, what is the work done in moving the second vehicle? We have

$$\begin{aligned} \mu &= 0.80; \\ W_2 &= 3000 \text{ lb}; \\ s &= 30 \text{ ft}; \end{aligned}$$

hence

$$e_4 = 0.8 \times 3000 \times 30 = 7.2 \times 10^4 \text{ ft-lb.}$$

**Summary:** We are now in a position to consider the whole problem of a collision of two vehicles. Despite the difficulties which have been repeatedly emphasized, it is possible to draw useful conclusions because of the premise that we are looking for a lower limit. The assumption that one of the vehicles is at rest should favor the defendant. We have seen that  $e_1$  and  $e_4$  are usually the only values calculable. Let us consider a practical problem where these values are involved.

**EXAMPLE.** The driver of car no. 1 on approaching car no. 2 applies the brakes and skids a distance of 20 ft before colliding with car no. 2. Subsequent to the collision no. 1 skids a further distance of 8 ft before coming to a stop. In the collision, no. 2, weighing 3000 lb, is knocked sideways a distance of 25 feet. The coefficient of friction of the roadway is 0.70. The weight of car no. 1 is 2500 lb. What is the least speed at which car no. 1 was traveling?

Considering the work done in skidding we have from equation (14)

$$e_1 = \mu W_1 s.$$

Substituting

$$\begin{aligned} \mu &= 0.70; \\ W_1 &= 2500 \text{ lb}; \\ s &= 20 + 8 = 28 \text{ ft}; \end{aligned}$$

we have

$$e_1 = 0.70 \times 2500 \times 28 = 49,000 = 4.9 \times 10^4 \text{ ft-lb.}$$



Considering the work done in moving car no. 2, we have

$$e_4 = \mu W_2 s$$

(where  $\mu$  is the sideways coefficient of friction).

Substituting

$$\mu = 0.70;$$

$$W_2 = 3000 \text{ lb};$$

$$s = 25 \text{ ft};$$

we have

$$e_4 = 0.70 \times 3000 \times 25 = 52,500 = 5.2 \times 10^4 \text{ ft-lb.}$$

The total energy  $E$  is, then, at least

$$E = e_1 + e_4 = 10 \times 10^4 \text{ ft-lb.}$$

Equation (12) may be rewritten as

$$v = \sqrt{\frac{2gE}{W}} \text{ (since } E \text{ has been expressed in ft-lb)}$$

Substituting, we have

$$v = \sqrt{\frac{2 \times 32 \times 10 \times 10^4}{2.5 \times 10^3}} = 51 \text{ fps}$$

or

$$v = 35 \text{ mph.}$$

## 8. THEORY OF BRAKING; TWO-WHEEL BRAKES <sup>27, 28</sup>

Problems in braking are not always as simple as the foregoing treatment would indicate. Frequently brakes are applied to only two wheels of a car and

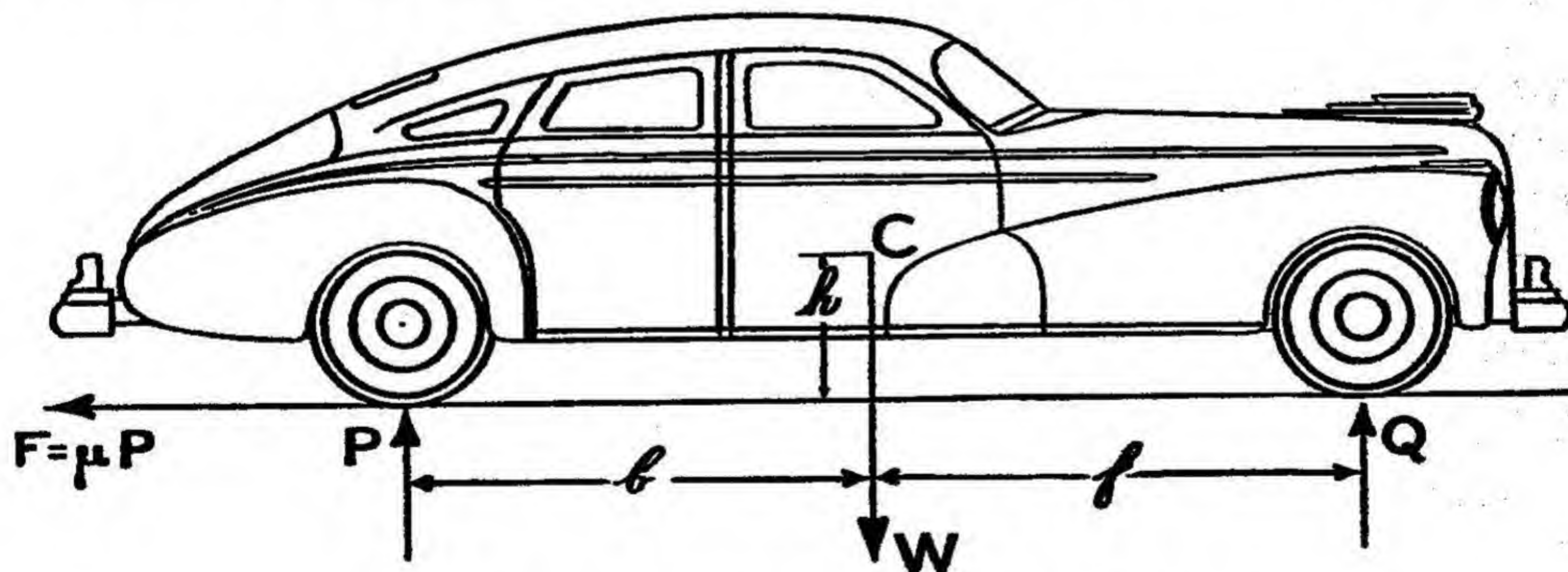


Fig. 189. Forces acting on a vehicle in braking.

the weight transfer must be taken into account. Sometimes, also, the wheels on the right side of the car will be on a different surface (different  $\mu$ ) from those on the left side. To solve these problems a more general theory of braking must be presented.

Figure 189 represents a car with two driving wheels, the revolving axle



turning the wheels in a given sense. If there were no friction between the surface of the tires and the surface of the roadway, the wheels would slip around and the car would not go forward. Friction, however, resists the tangential motion between bodies in contact. In the case of the driving wheels, friction opposes the rotation of the wheels and the frictional force drives the car forward. This propulsive force cannot be greater than  $\mu P$ , where  $P$  is the force of the driving wheels on the ground.

Considering now the other pair of wheels which is not driven, we notice that without friction these wheels would slide forward and would not rotate. The friction between the tires and the surface of the ground causes the wheels to rotate. For this purpose the frictional force must be in the opposite direction to the motion of the car. The force is merely sufficient to rotate the wheels and is consequently much smaller than the frictional force on the driving wheels.

On applying the brakes, the bands grip a smaller concentric wheel fixed to the running wheel. Another set of frictional forces is set up, which opposes the rotation of the wheels. The frictional force now, however, is along the same direction as the frictional force on the nondriving wheels, opposing the motion of the car. The frictional force due to the brakes cannot exceed  $\mu P$ , where  $P$  is the force between the wheels and the road, without causing the wheels to skid. If a car has four-wheel brakes the maximum braking force is  $\mu W$ , where  $W$  is the weight of the car.

To measure the retarding force when brakes are applied to one pair of wheels, we must consider the manner in which the division of weight between the wheels is affected by the braking action. In Fig. 189 let  $C$  be the center of gravity of the car. We shall neglect the inertia of the wheels and the negligible frictional forces between them and the ground. Let  $f$  and  $b$  be the horizontal distances of the center of gravity from the front and rear axles respectively, and let  $h$  be the height of the center of gravity above the ground. Let  $P$  and  $Q$  be the reactions between the ground and the rear and front wheels, respectively. If  $a$  is the deceleration produced by braking the rear wheels, a frictional force of  $Wa/g$  (since  $W = mg$ , where  $m$  is the mass of the car) opposes the motion of the car.

Since the upward acting forces on the car must equal the downward acting force (the weight),

$$P + Q = W.$$

The turning effect of these forces about  $C$ , taken as an axis of rotation, must balance; so

$$bP + \frac{hWa}{g} = fQ.$$

Solving for  $P$  and  $Q$  and setting  $f + b = L$ , the distance between the axles, we have

$$P = W \frac{fg - ha}{gL} \quad (15a)$$



and

$$Q = W \frac{bg + ha}{gL} \quad (15b)$$

From previous statements we know that the braking force cannot exceed  $\mu P$ . But this braking force is  $Wa/g$ . Therefore,

$$Wa/g \leq \mu P.$$

Substituting for  $P$ , we have

$$a \leq \frac{\mu fg}{L + \mu h}.$$

In the notation of the calculus it can be shown that

$$a = v \frac{dv}{ds}$$

or

$$ads = vdv.$$

Substituting, now, for  $a$  its maximum value

$$a = -\frac{\mu fg}{L + \mu h},$$

which is negative because it is a deceleration, we have on integrating

$$\int_0^v v dv = -\int_0^s \frac{\mu fg}{L + \mu h} ds,$$

giving

$$v = \sqrt{\frac{2\mu fgs}{L + \mu h}} \quad (16)$$

This then is the equation which will give the initial velocity  $v$  in terms of stopping distance  $s$  when rear-wheel brakes alone are applied. A similar procedure for front-wheel brakes alone will give

$$v = \sqrt{\frac{2\mu bgs}{L - \mu h}}.$$

If the vehicle is operable, test (a) can be used and equation (7) applied. In this case nothing need be known of the other constants in equation (16). When, however, the car cannot be operated in its original condition, it is necessary to determine the constants  $\mu$ ,  $f$  (or  $b$ ),  $L$ , and  $h$ . The measurement of  $\mu$  has already been discussed;  $L$  is readily measured. The determination of the values of  $h$ ,  $f$ , and  $b$  is less simply accomplished, as will be seen below.

## 9. WEIGHT TRANSFER

We may simplify the above discussion somewhat by using the terms which are employed in engineering. We can rewrite equations (15a) and (15b) as follows

$$P_R = \frac{Wf}{L} - \frac{W\mu h}{L}$$



and 
$$Q_E = \frac{Wb}{L} + \frac{W\mu h}{L},$$

where the subscript  $E$  is used to indicate that  $P_E$  and  $Q_E$  are the *effective weights* on the rear and front wheels, respectively, and  $\mu$  has been substituted for  $a/g$ . In Fig. 189 we can, by taking moments about the rear and front wheels respectively, derive the following equations for the *static weights* (denoted by subscript  $s$ ) on the rear and front wheels. Thus,

$$P_s = \frac{Wf}{L}$$

and

$$Q_s = \frac{Wb}{L}.$$

Substituting these values in equations (15a) and (15b), we have

$$P_E = P_s - \frac{W\mu h}{L} \quad (17)$$

and

$$Q_E = Q_s + \frac{W\mu h}{L}. \quad (18)$$

These equations express the fact that in decelerating there is a shift of weight on each wheel of the vehicle. The weight on the front wheels is increased and that on the rear wheels is decreased. The change in weight is equal and opposite. The increase or decrease is called the *weight transfer* and is defined thus:

$$\text{Weight transfer} = \frac{W\mu h}{L} \quad (19)$$

The concept of weight transfer is useful in cases where the skidmarks of different wheels vary greatly in length and also where the wheels on one side of the vehicle skidded on a different surface from those of the other side, e.g., a car on the shoulder of the road with one side on gravel and the other side on concrete. The average passenger vehicle is constructed so that approximately 0.3 of the total weight is on each front wheel during braking and 0.2 of the weight is on each rear wheel.

In order to compute the initial speed in cases of this nature, the braking force due to each wheel must be calculated separately. Equations (15a and b) can be employed. For example, the force on the rear right wheel would be one-half the value given by equation (15a). The sum of the forces on each wheel is thus computed. This sum is used instead of  $P$  to arrive at a relation similar to equation (16). The appropriate values of  $\mu$  and  $s$  are substituted for each wheel and  $v$  is computed.

In place of this somewhat lengthy procedure, a simplified formula is sometimes used.<sup>30</sup> When the operations described in the preceding paragraph are performed, equation (16) assumes the following form:

$$v = \sqrt{30(\mu_1 M_{fs1} + \mu_2 M_{fs2} + \mu_3 M_{bs3} + \mu_4 M_{bs4})}.$$



In this equation the subscript 1 refers to the left front wheel; 2 refers to the right front; 3 to the right rear; and 4 to the left rear.  $M$  is called the *weight factor* and is determined by the distribution of weight in braking as indicated in equations (15a and b).  $M_f$  and  $M_b$  are the weight factors for the front and rear wheels respectively. The average passenger vehicle is constructed so that  $M_f = 0.3$  and  $M_b = 0.2$ ; i.e., 0.3 of the total weight is on each front wheel during braking, and 0.2 of the weight is on each rear wheel. The sum of the  $M$ 's is, of course, equal to unity. This assumption of the distribution of weight greatly simplifies the calculations for a passenger vehicle as will be seen from the following example.

**EXAMPLE.** An accident car skids with the right wheels on the shoulder of the road. The following skidmarks are recorded: left front wheel — 72 ft; right front — 84; right rear — 64; left rear — 64. The coefficient of friction is found to be 0.81 on the road and 0.52 on the shoulder. It is assumed that the weight distribution in braking is 30 per cent on each front wheel and 20 per cent on each rear wheel. Find the initial speed of the car.

Substituting the values

$$\mu_1 = \mu_4 = 0.81; \mu_2 = \mu_3 = 0.52; M_f = 0.3; M_b = 0.2;$$

$$s_1 = 72; s_2 = 84; s_3 = 79; s_4 = 65; \text{ we have}$$

$$v = \sqrt{30(0.81 \times 0.3 \times 72 + 0.52 \times 0.3 \times 84 + 0.52 \times 0.2 \times 79 + 0.81 \times 0.2 \times 65)}$$

or

$$v = 38 \text{ mph.}$$

## 10. DETERMINING THE POSITION OF THE CENTER OF GRAVITY OF A VEHICLE<sup>31, 32</sup>

Several methods are applicable in determining  $C$ , the position of the center of gravity. One of these is described here. To locate  $C$ , the center of gravity, three measurements of the weight are needed: (a)  $W$ , the weight of the car on level ground; (b)  $W_1$ , the weight on the rear wheels when the car is on level ground; (c)  $W_2$ , the weight on the rear wheels when the front wheels of the car are elevated by block and tackle at the axle.

Figure 190 represents the vehicle in the two positions of weighing.  $C$  is the center of gravity;  $CD = h - r$ , the height of the center of gravity from plane of axles;  $AB = L$ , the distance between axles;  $AD = f$ , the distance from the front axle to the plumb line through  $C$ ; ( $BD = b$ , a similar measurement for the rear axle)  $AE = y$ , the elevation of the front wheels in the second position;  $BE = \tilde{z}$ , the horizontal projection of  $L$  in the second position;  $r$  = height of axle from ground.

In Fig. 190(a), taking moments about  $A$ , we have

$$W \times f = W_1 L$$

or

$$f = \frac{W_1}{W} L \quad (20)$$

and

$$b = L \left( 1 - \frac{W_1}{W} \right).$$



In Fig. 190(b), again taking moments about  $A$  we have

$$W \times C'A = W_2 \times Z \quad (21)$$

where  $C'A$  is drawn parallel to the horizontal.

From the relations

$$\cos \theta = \frac{C'A}{KA} = \frac{BE}{BA}$$

$$KA = KD + DA$$

and

$$\tan \theta = \frac{KD}{CD} = \frac{AE}{BE}$$

It is easily shown that

$$C'A = \frac{(h - r)y + fZ}{L}$$

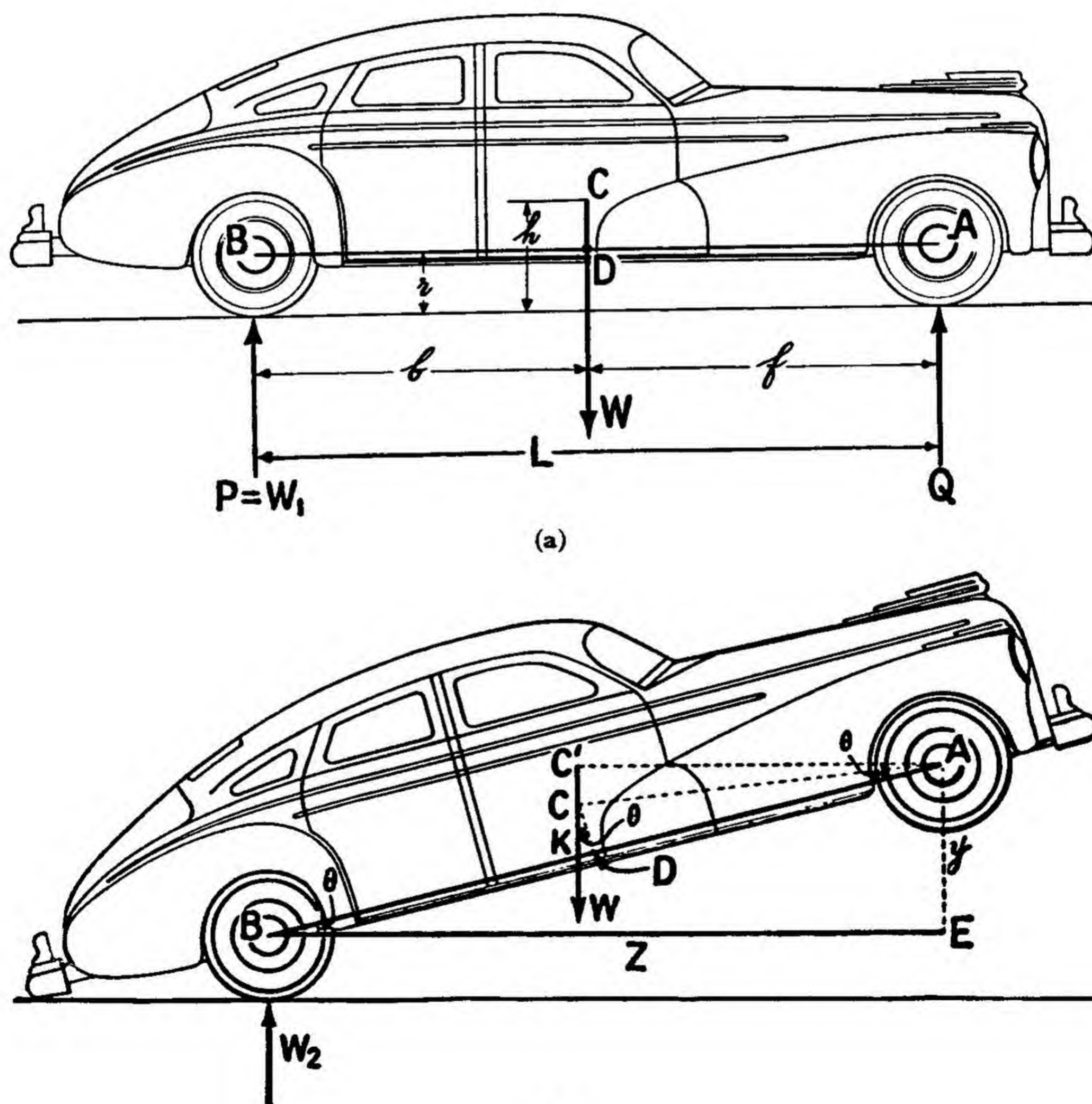


Fig. 190. (a) Determining the center of gravity — weighing the vehicle in the horizontal position; (b) weighing the vehicle suspended from the front wheels.



Substituting in equation (21) and solving for  $h$ , we have

$$h = \frac{\sum}{v} \left( L \frac{W_2}{W} - f \right) + r$$

or, by means of equation (20),

$$h = \frac{\sum L}{vW} (W_2 - W_1) + r. \quad (22)$$

The height of the center of gravity of the average passenger car is approximately 24 in.

## 11. ACCIDENTS ON CURVES <sup>33, 34, 35, 36</sup>

A common cause of accidents is excessive speed on curves. A bus, for example, may be found at the bottom of an embankment; at what speed must the bus have been traveling around the curve so that it would overturn? Again, in rounding a curve, a car strikes a person; could the driver have been exceeding the legal speed limit?

A few of the physical principles which guide the behavior of vehicles in such accidents will be treated. The treatment is necessarily simplified. The action of a vehicle on a curve requires a much lengthier discussion when all the factors are considered. An understanding of the following fundamental problems, however, will suffice in most cases to indicate negligence: (a) At what speed must a vehicle take an unbanked curve in order to overturn? (b) At what speed will the tendency to side slip be eliminated for a banked curve the slope of which is  $\tan \theta$ , and which does not offer frictional resistance? (c) The same

question as (b) with frictional force present.

It is not proposed that the methods described below be used in litigations or prosecutions. There are too many variables in the problems to permit uncritical use of the formulas. The methods will, however, serve well in investigations for vehicle fleets.

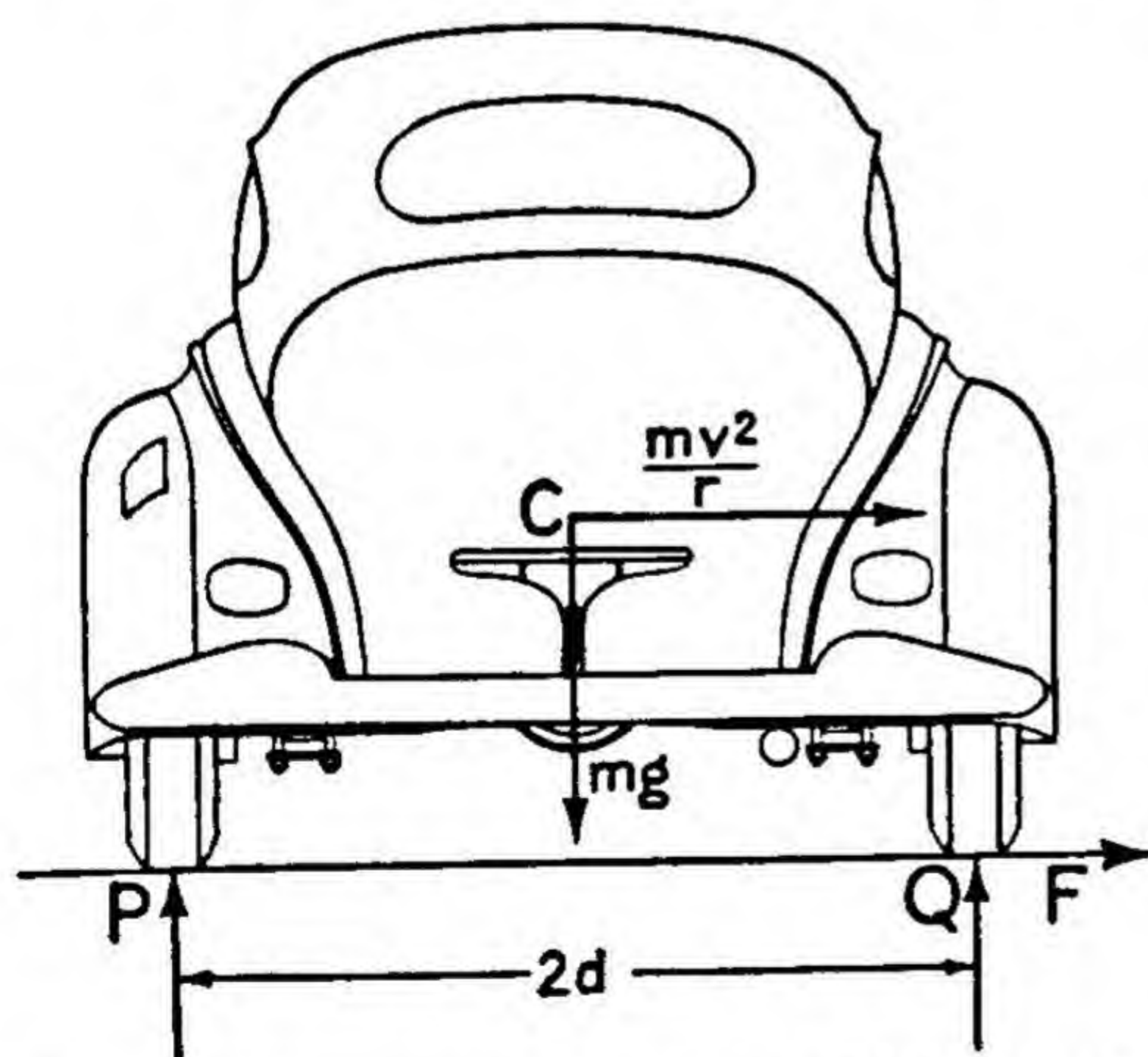


Fig. 191. Forces acting on a vehicle traveling along a curve.

### Unbanked Curves

Figure 191 represents a car with center of gravity  $C$  describing a curve of which the radius of curvature is  $r$ .  $P$  and  $Q$  represent the reaction of the ground on the outer

and inner wheels respectively;  $F$  is the frictional force across the road;  $h$  is the height of the center of gravity;  $2d$  is the distance between the wheels. Inward along the normal to the curve, which it is describing, the center



of gravity has an acceleration  $\frac{v^2}{r}$ . This acceleration requires a force — in this case the centripetal force. Friction supplies such a force. The reaction to this is the centrifugal force. Hence, equating these two we have

$$F = \frac{mv^2}{r}.$$

Since there is no angular momentum about  $C$ , (except about the vertical axis) we have, by taking moments about  $C$ ,

$$(P - Q)d = Fh$$

or

$$P - Q = \frac{mv^2h}{rd}.$$

Resolving vertically

$$P + Q = mg;$$

therefore

$$2P = mg + \frac{mv^2h}{rd}$$

and

$$2Q = mg - \frac{mv^2h}{rd}.$$

If  $Q$  is negative, the inner wheels exert no pressure on the ground and the car overturns. The condition for a negative  $Q$  is

$$v^2 > \frac{grd}{h}. \quad (23)$$

Hence, if

$$v > \sqrt{\frac{grd}{h}},$$

the car will overturn.

It should be noticed that this critical speed is independent of the mass of the car. The measurement of  $h$  has already been treated. The value of  $r$  will be found in the official records. In general, it will be found that  $r$  is not a constant for any considerable section of the curve.

**EXAMPLE.** A vehicle of 4 ft width between wheels and center of gravity 24 in. from the ground overturns on an unbanked curve at a point where the radius of curvature is 78 ft. At what minimum speed must the vehicle have passed this point?

Substituting the following values

$$g = 32 \text{ fps per sec};$$

$$r = 78 \text{ ft};$$

$$d = 2 \text{ ft};$$

$$h = 2 \text{ ft};$$

$$v = \sqrt{\frac{32 \times 78 \times 2}{2}} = 50 \text{ fps}$$

$$v = 34 \text{ mph.}$$



### Banked Curves Without Friction

To lessen the danger of the car's skidding, a curve is banked to an angle  $\theta$ . We investigate now the value of  $\theta$  which will prevent sideslip. If there were no sideways friction, what should be the lateral gradient in order to prevent skidding to the side?

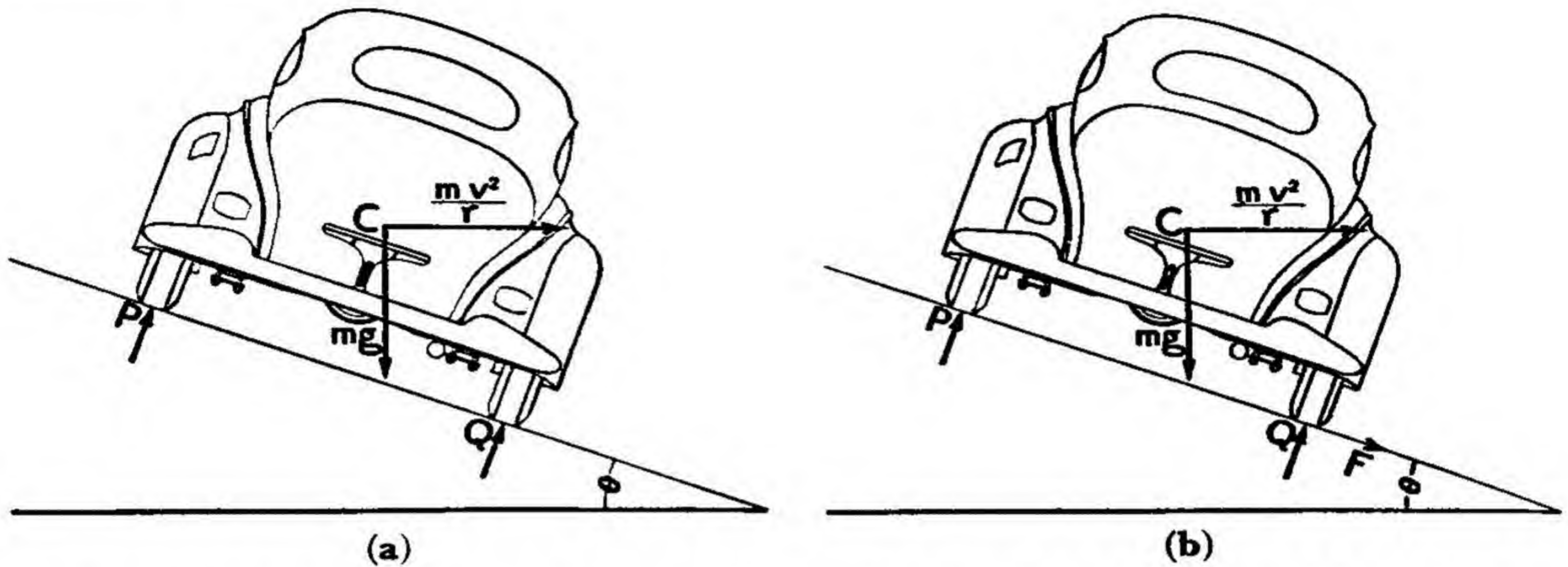


Fig. 192. (a) Forces acting on a vehicle traveling along a banked curve without friction; (b) Forces acting on a vehicle traveling along a banked curve with friction.

In Fig. 192(a) the symbols will have the same meaning as those of Fig. 191. Resolving horizontally,

$$\frac{mv^2}{r} = (P + Q) \sin \theta;$$

and vertically,

$$mg = (R + S) \cos \theta.$$

Dividing one equation by the other,

$$\tan \theta = \frac{v^2}{rg}.$$

The velocity  $v_c$  at which the car will have no tendency to sideslip is

$$v_c = \sqrt{rg \tan \theta}. \quad (24)$$

**EXAMPLE.** A truck is traversing a curve at a point where the radius of curvature is 60 ft and the road is banked at an angle of  $10^\circ$ . If the road is extremely slippery what is the maximum safe speed?

Substituting the following values:

$$r = 60 \text{ ft};$$

$$g = 32 \text{ fps per sec};$$

$$\tan 10^\circ = 0.18;$$

we have

$$v = \sqrt{60 \times 32 \times 0.18} = 18 \text{ fps}$$

or

$$v = 12 \text{ mph.}$$



If the speed is greater than this the car will skid outward; if it is less, the skid will be inward. The driver must depend upon friction between the tires and the road to prevent this skidding. The danger of wet or icy curves is obvious.

Again, the mass of the car does not enter into the equation. The tendency of a light and a heavy car to skid is the same; the bank is the same for all cars. Another point of interest is the absence in the equation of any term involving the height of the center of gravity. Skidding is independent of the position of the center of gravity; overturning, however, does depend on the height of the center of gravity.

The values of  $\theta$  and  $r$  can be obtained from the records of official sources or calculated.

### Banked Curves with Friction

We have seen in the preceding problem that, on a curve banked to prevent side skidding, there is a definite speed,  $v_0$ , at which this skidding will not occur. The force of friction, however, was ignored. The question then arises: When there is friction between the tires and the roadway, at what greater speed,  $v_1$ , can a car travel on a curve without sideslip?

In Fig. 192b the symbols will have the same significance as in the previous figures.

Resolving horizontally,

$$\frac{mv_1^2}{r} = (P + Q) \sin \theta + F \cos \theta.$$

Resolving vertically,

$$mg = (P + Q) \cos \theta - F \sin \theta.$$

Moreover,  $F = \mu N$ , where  $N$  is the pressure normal to the plane of the road.

The components of force normal to the road are

$$N = mg \cos \theta + \frac{mv_1^2}{r} \sin \theta.$$

Eliminating  $(P + Q)$  from the first two equations, we have

$$\frac{mv_1^2}{r} - mg \tan \theta = F \sec \theta$$

or, since  $F = \mu N$ ,

$$\frac{mv_1^2}{r} - mg \tan \theta = \mu \left( mg + \frac{mv_1^2}{r} \tan \theta \right).$$

But, from equation (24),

$$rg = \frac{v_0^2}{\tan \theta};$$

hence

$$\frac{v_1^2}{v_0^2} \tan \theta - \tan \theta = \mu \left( 1 + \frac{v_1^2}{v_0^2} \tan^2 \theta \right).$$

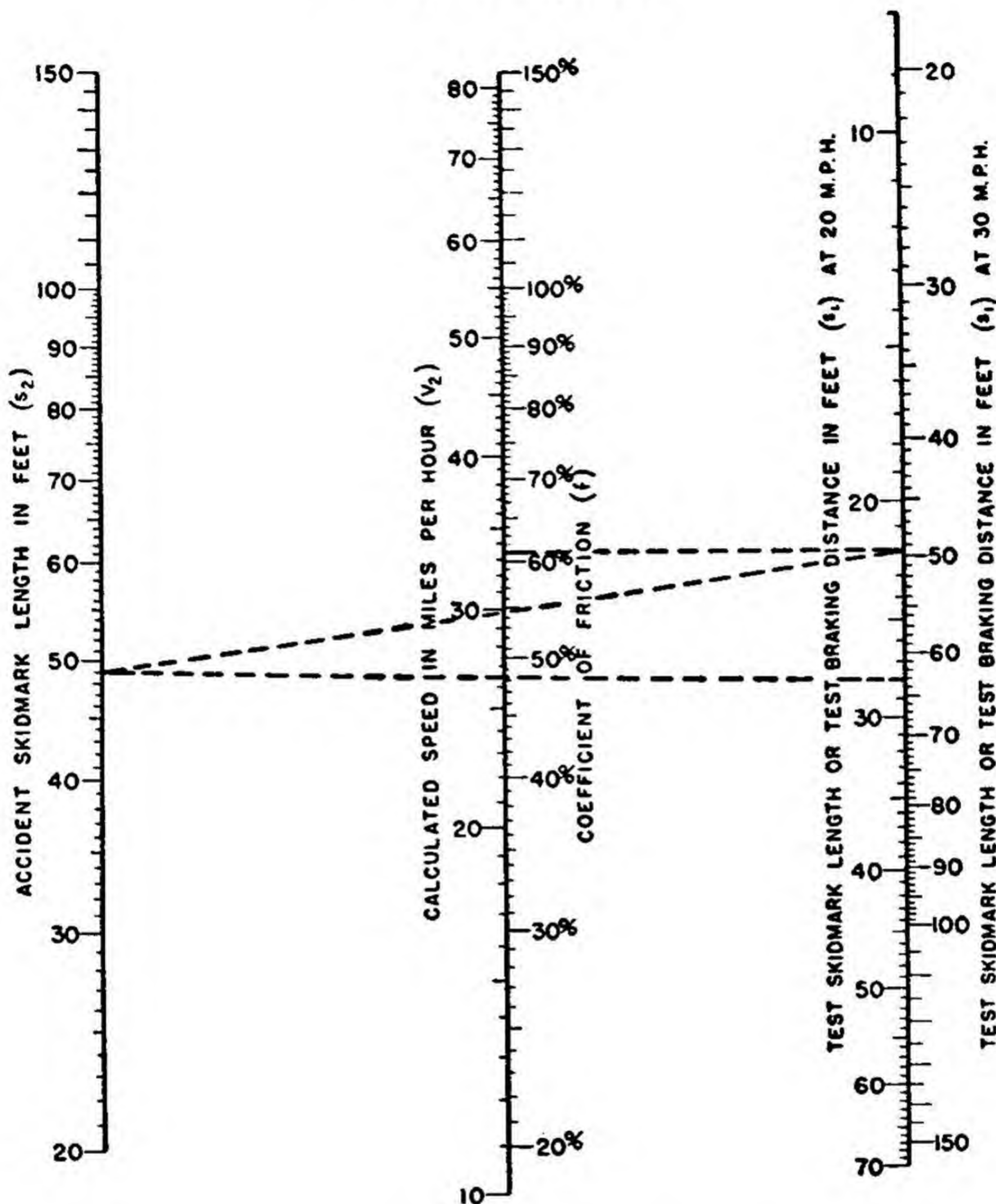


Solving for  $v_2$ ,

$$v_2 = v_1 \sqrt{\frac{1 + \mu \cot \theta}{1 - \mu \tan \theta}},$$

or

$$v_2 = \sqrt{rg \frac{\mu + \tan \theta}{1 - \mu \tan \theta}}. \quad (25)$$



BASED UPON A CHART BY AMERICAN AUTOMOBILE ASSOCIATION  
AMERICAN TRANSIT ASSOCIATION SEPT. 1940

Fig. 193(a). Chart I.

At a speed greater than  $v_2$  the car will have a tendency to slide off the road.

**EXAMPLE.** At a certain turn in a concrete highway of frictional coefficient 0.75 the curve is banked at an angle of  $8^\circ$ . The radius of curvature at this point is 50 ft. At what maximum speed may a car safely pass this curve?

Substituting

$$\begin{aligned} r &= 50 \text{ ft;} \\ g &= 32 \text{ fps per sec;} \\ \mu &= 0.75; \\ \tan \theta &= 0.14; \end{aligned}$$

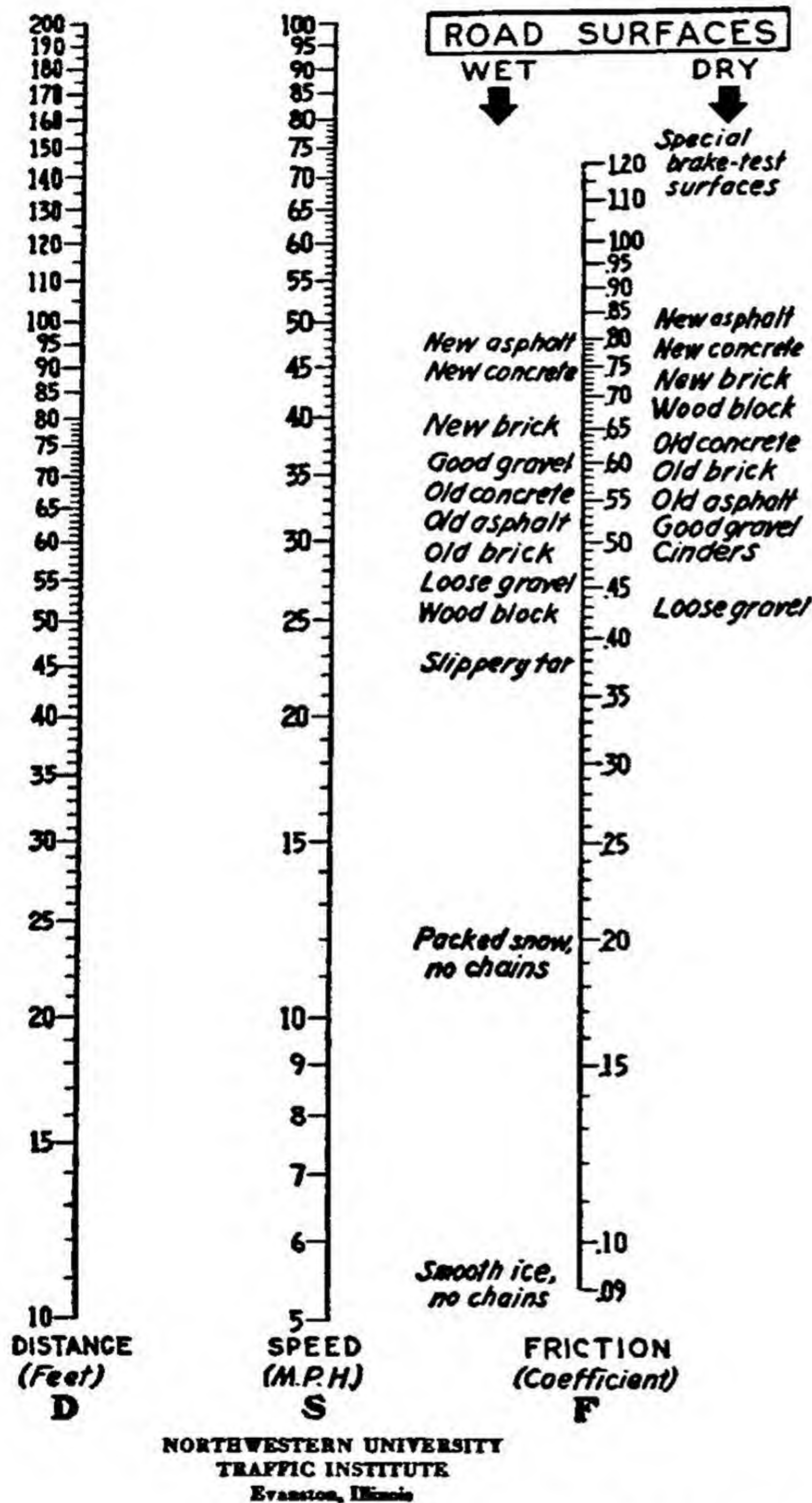


we have

$$v = \sqrt{50 \times 32 \left( \frac{0.75 + 0.14}{1 - 0.75 \times 0.14} \right)} = 40 \text{ fps,}$$

or

$$v = 27 \text{ mph.}$$



### HOW TO ESTIMATE SPEED FROM SKID MARKS.

1. Find the coefficient of friction. With test skid; locate the average test skid mark length on scale D. Draw a straight line from this point through the test speed on scale S to scale F, where the coefficient of friction as determined by the test skid is found.

Without test skid: an estimate should be made only when all four wheels have skid marks. Locate the approximate coefficient of friction on scale F directly opposite the most suitable pavement description.

2. Find the estimated speed before accident. From the coefficient of friction on line F, found as described above, draw a straight line to the average accident skid mark length on scale D. Where this line crosses scale S is the indicated speed of the vehicle involved in the accident.

3. Remember that special calculations are required when part of the skidding is on one kind of pavement and part on another, when the skid was uphill or downhill.

Fig. 193(b). Chart II.

### Chart I

The calculations involved in employing an equation such as  $v_2 = v_1 \sqrt{\frac{s_2}{s_1}}$  can be simplified by graphs. Chart I (Fig. 193a) has been drawn for test speeds of 20 or 30 mph. When  $s_2$  and  $s_1$  are connected by a straight line,  $v_2$  can be determined by the intersection of the line with the center scale. For example, in the case of an accident skidmark of 49 ft the test skid at 20 mph is found to



be 22 ft. On connecting 49 on the left scale with 22 on the right, we find the line intersecting the center scale at 29.8 mph. This is the *minimum* speed. If the *braking* distance were 28 ft, we should find a speed of 26.5 mph in a similar manner.

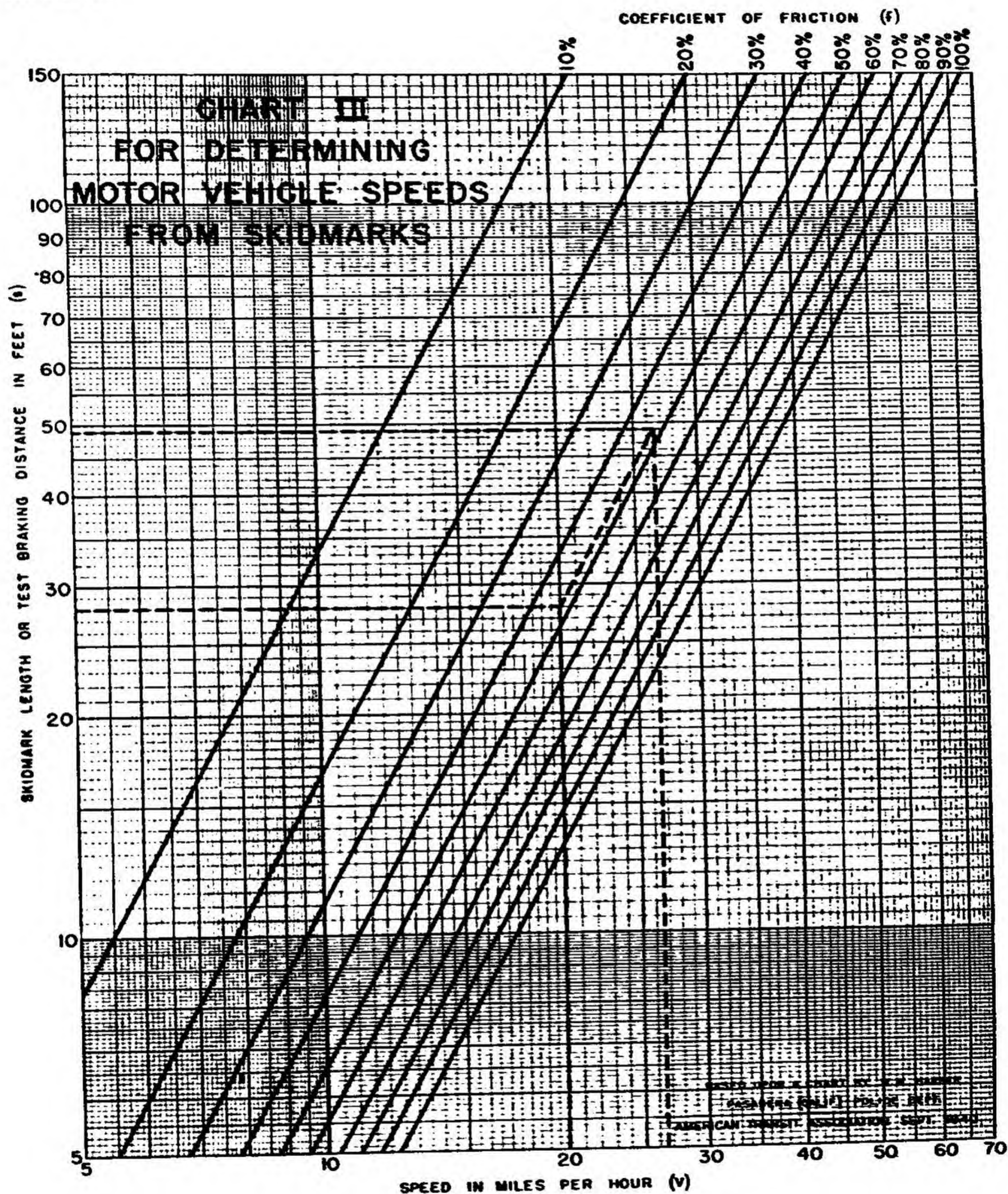
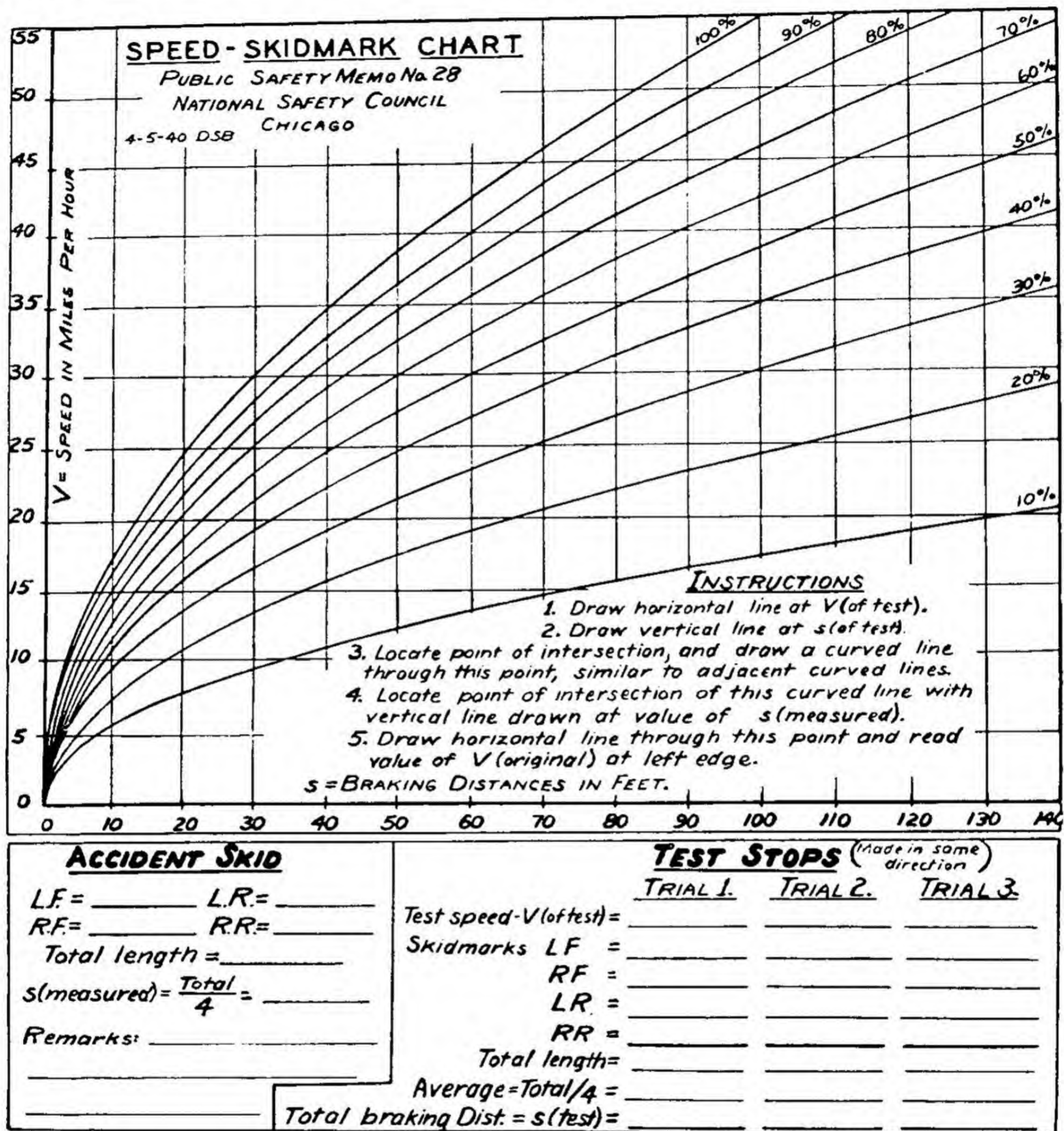


Fig. 194. Chart III.

This chart can be used also to determine the coefficient of friction in the following manner: From the point where the original line intersects the right



scale, draw a horizontal line to the center scale and read off the coefficient. For example, using the braking distance of 22 ft we find that the horizontal line intersects the scale at 61 per cent. This represents a coefficient of 0.61.



Accident location \_\_\_\_\_  
 Pavement type \_\_\_\_\_ Condition \_\_\_\_\_ Grade \_\_\_\_\_ %  
 Time and date \_\_\_\_\_  
 Driver \_\_\_\_\_  
 Vehicle (make, model, Type, Lic. No.) \_\_\_\_\_  
**MINIMUM SPEED** =  $V(\text{original}) =$  \_\_\_\_\_ M.P.H.  
 Investigator: \_\_\_\_\_

Fig. 195.

Chart II

This chart (Fig. 193b) is similar to Chart I. Its use is explained at the side.



*Chart III*

This graph (Fig. 194) serves the same purpose as Charts I and II. A vertical line is drawn at the test speed  $v_1$  until it intersects a horizontal line drawn through the test skidmark or the braking distance  $s_1$ . (This procedure is equivalent to plotting the point  $v_1, s_1$ .) Through this point a line is drawn parallel to the diagonal lines until it intersects the horizontal line corresponding to the accident skidmark  $s_2$ . A vertical line drawn at this intersection will intercept the speed axis at the accident speed. In Chart III these lines have been drawn for the case of a test speed of 20 mph, a test braking distance of 28 ft, and an accident skidmark of 49 ft. The result lies between 26 and 27 mph.

**EXERCISES**

1. A force of 1500 lb is required to pull a car weighing 2500 lb over a roadway. What is the coefficient of friction between the tires and the roadway?
2. Transform the equation

$$\mu = \frac{v^2}{2gs}$$

where  $v$  is in fps,  $g$  is 32 fps per sec, and  $s$  is in feet, into

$$\mu = \frac{v^2}{30s}$$

where  $v$  is in mph and  $s$  is in feet.

3. On applying the brakes fully, a skidmark of 139 ft is made by a vehicle traveling on a concrete road. The coefficient of friction of the road is 0.60. At what speed was the vehicle traveling when the brakes were applied?

4. In ascending a hill of gradient  $\frac{1}{\sqrt{3}}$ , a vehicle is brought to a stop in a braking distance of 10 ft. The coefficient of friction is 0.60. How fast was the car traveling?

5. At the scene of an accident the length of the skidmark is found to be 80 feet. By operating the car at 30 mph and applying the brakes fully, a braking distance of 30 ft is required to stop the car. What was the initial speed of the car at the time in question?

6. In descending a hill, a car makes a skidmark of 140 ft, of which 62 ft is made on level ground. The hill has a gradient of 0.56. Using the same car on level ground a braking distance of 40 ft is required in stopping the car from a speed of 30 mph. From what speed was the original skidmark made? (Using equation (4), form an equation similar to equation (6); thus

$$v_1 = v_2 \sqrt{\frac{L_1(\mu \cos \alpha - \sin \alpha) + \mu s_1}{s_2}}$$

where  $L_1$  is the part of the mark on the hill and  $s_1$  is the part on level ground.)

7. Two cars are involved in a collision. Car no. 1 applies the brakes and skids 12 ft before colliding with car no. 2, which was parked with the emergency brake on. Car no. 2, which weighs 2000 lb is pushed forward a distance of 15 ft. Car no. 1 continues skidding a distance of 4 ft. The coefficient of friction of the road is 0.80. At what speed was car no. 1 traveling when the brakes were applied?



8. A certain type truck is 4 ft wide between wheels and has a center of gravity 30 in. above ground. On an unbanked curve at a point where the radius of curvature is 76 ft, the truck overturns. At what minimum speed must the vehicle have passed this point?

9. At what angle must the road described in exercise 8 be banked in order to permit the vehicle in question to travel at a speed of 45 mph without overturning?

10. At what angle must the road of exercise 8 be banked to prevent sideslip for a speed of 40 mph, assuming there is no friction?

11. At what angle must the road of exercise 8 be banked to prevent sideslip for a speed of 40 mph if the coefficient of friction is 0.68?

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# PART F

## CHEMICAL EXAMINATIONS







# CHAPTER 26

## CHEMICAL TESTS FOR INTOXICATION

### 1. BLOOD ALCOHOL AS AN INDEX OF INTOXICATION

Within the last decade an objective method has been developed for determining, in relation to automobile driving, when a person is "under the influence" of alcohol. A correlation between the degree of impairment of a person's mental and physical faculties by alcohol and its concentration, determined chemically, in certain body materials has been established authoritatively by two groups,<sup>1, 2, 3</sup> the *Committee to Study Problems of Motor Vehicle Accidents* of the American Medical Association, and the *Committee on Tests for Intoxication* of the National Safety Council.

The findings of these committees are shown in Table 14. These criteria were based upon a critical review of the literature reporting the results of a great many investigators in several countries who studied the problem of using the percentage of alcohol in various body fluids as an index of intoxication.

**TABLE 14. An Interpretation of "Under the Influence" in Relation to Automobile Driving**

BLOOD ALCOHOL PER CENT *	SIGNIFICANCE
0.00-0.05 (Zone 1)	Insufficient to exert any significant influence on a person's ability to drive.
0.05-0.15 (Zone 2)	Some persons will be "under the influence"; others not; as the higher limit is approached, more are affected. It is questionable whether one should drive or not; other evidence must be considered.
above 0.15 (Zone 3)	All persons are "under the influence" of the alcohol insofar as their ability to drive is concerned.

\* The concentration of alcohol in the blood is referred to as *blood alcohol per cent*, *blood alcohol level*, or *per cent blood alcohol*. These terms are synonymous and refer to the weight of alcohol in mg per ml of blood divided by 10. Mathematically, this ratio is equivalent to grams per 100 ml. Regardless of the body substance analyzed, the results are always expressed in terms of percentage of alcohol in the blood.



### Zone 1

Blood alcohol values in this zone are usually considered as evidence that a person is *not* under the influence of alcohol.

An average male (150–175 lb) on an empty stomach may drink 2 oz of 100 proof whiskey (one highball) or a little over one large bottle of beer (1–1½ qts) before his blood alcohol level reaches 0.05 per cent (see Table 15). After a meal these quantities may be increased somewhat, and in some cases double these quantities may be taken with the same effect.<sup>4</sup>

### Zone 2

Blood alcohol values in this zone are inconclusive by themselves. They are useful in showing that a person had “been drinking”; if the usual external symptoms of intoxication are present, they are useful as corroboratory evidence that a person is under the influence of alcohol.

An average male (150 lb) would have to drink about 8 to 10 oz of 100 proof whiskey (4 to 5 highballs) to accumulate 0.15 per cent alcohol in the blood<sup>5</sup> (see Table 15).

### Zone 3

Blood alcohol values in this zone are considered *prima facie* evidence that a person is under the influence of alcohol sufficiently to impair his driving ability.

Persons who “carry their liquor well” may appear sober to the average eye, yet from the standpoint of driving an automobile they are a menace if their blood level is in this zone. These persons might have to drink 12 oz of 100 proof whiskey (6 highballs) before their blood alcohol reaches 0.15 per cent.<sup>6</sup>

By establishing upper (0.15) and lower (0.05) limits, it is possible to overcome many objections which might be raised in connection with using the concentration of alcohol in body fluids as an index of intoxication. Zone 1 protects those who, because of some congenital or acquired defect, or pathological condition, exhibit some of the usual symptoms of intoxication such as flushed face, dilated pupils, faltering speech, tremor, and lack of muscular coordination and who might, therefore, be wrongly accused of being intoxicated. Similarly it is possible to verify or disprove any contention made by the defendant that he only appeared to have been drinking but in reality was suffering from the shock or injury of the accident. In these cases, if an alcoholic odor on the breath is noticed, the claim is usually made that the defendant had taken “one or two beers.” This can be verified or disproved in many cases.

Zone 3, on the other hand, provides for the detection of those individuals who, because of the sudden stimulus which sometimes occurs after an accident and which may be sufficient to overcome the depressing effect of the alcohol, appear to be sober since the usual symptoms of intoxication are not discernible.

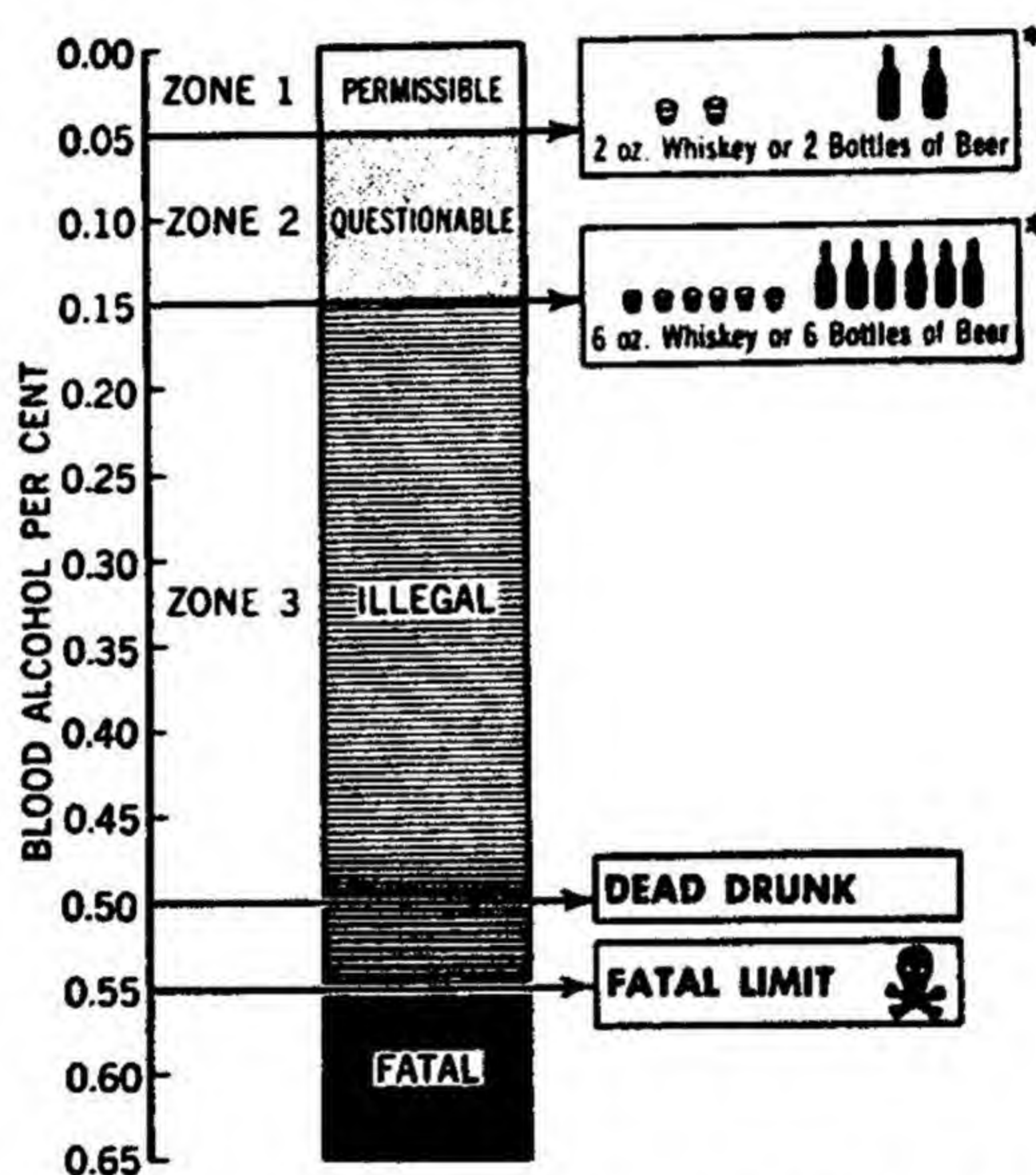


## 2. CHEMICAL TESTS

The literature of the chemicolegal tests for alcohol is voluminous. There are almost as many variations in procedure as there are investigators interested in the problem. Fundamentally, however, almost all procedures are based upon oxidation of the alcohol to acetic acid under controlled conditions. The most common oxidant employed is potassium dichromate in acid solution<sup>7</sup> (equation 1) although potassium permanganate both in acid<sup>8</sup> and alkaline medium<sup>9</sup> is sometimes used.



**TABLE 15**  
**Blood Alcohol Zones**



\* The figures in these boxes represent the amount of 100 proof whiskey or 4 per cent beer accumulated in the body of an average motorist (a 150-male, on an empty stomach) when his blood alcohol reaches the limits indicated. (Courtesy, R. N. Harger and the Indiana State Police.)

*Ox* is a symbol used to represent an oxidant such as dichromate or permanganate, while *Rd* represents the reduced form of the oxidant; *a*, *b*, and *c* represent the numerical coefficients required to balance the equation. In the case of alkaline permanganate the alcohol is oxidized to oxalic acid and not to acetic acid.

Since both dichromate and permanganate undergo a color change when they are reduced, a color comparator may be used to estimate the quantity of alcohol present. Usually, however, the oxidant is added in excess and is back-titrated with any of the usual reducing agents, e.g., iodide, oxalate, or ferrous ion. It has also been suggested that the acetic acid may be used to estimate the



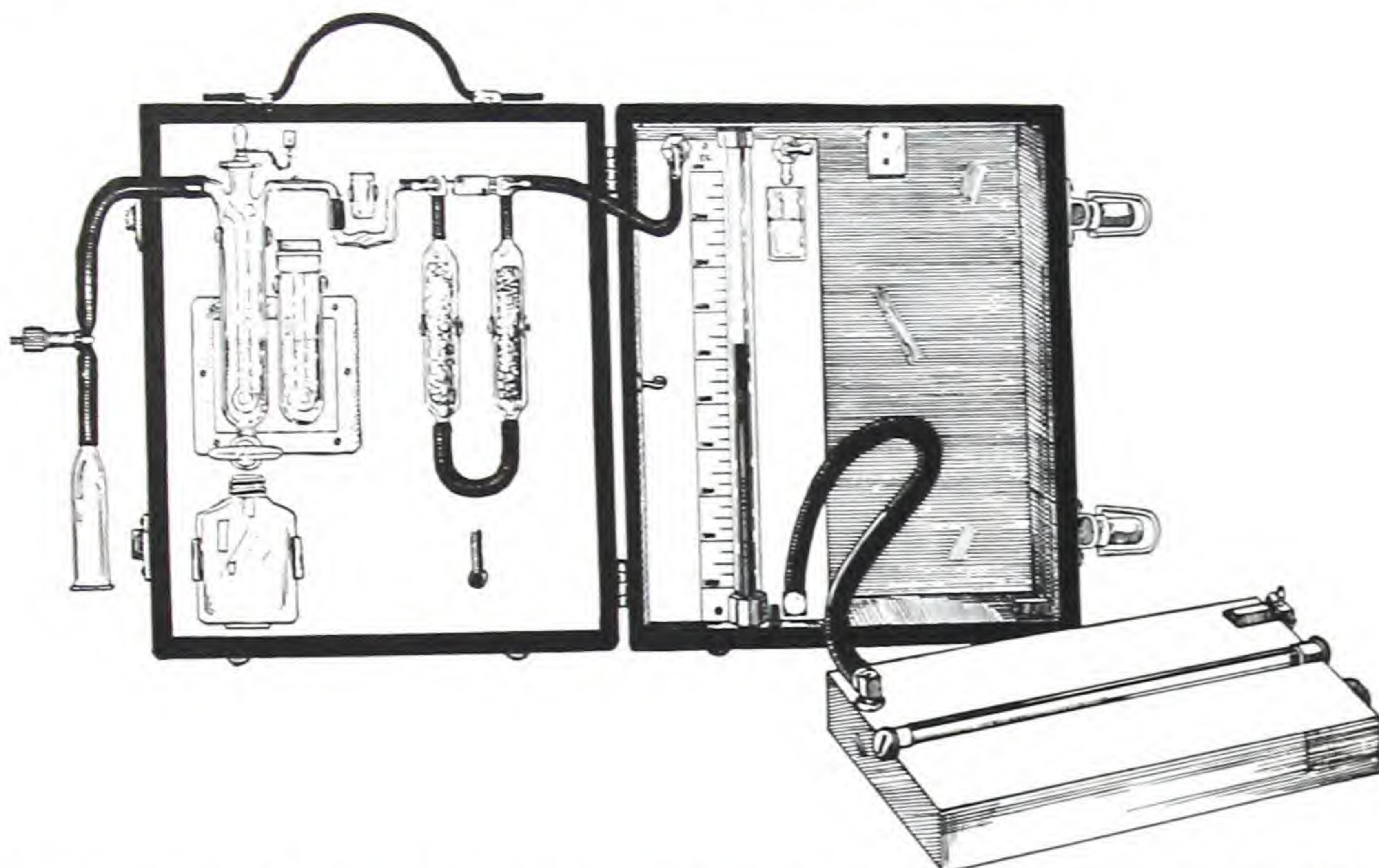


Fig. 196(a). The Harger Drunkometer: schematic drawing. (Courtesy, Indiana State Police.)



Fig. 196(b). The Harger Drunkometer: in field use. (Courtesy, Indiana State Police.)



amount of ethyl alcohol.<sup>10</sup> After distillation of the reaction mixture, the amount of acetic acid is determined by titration of the distillate. When ethyl alcohol is determined by methods<sup>11</sup> that employ iodine pentoxide, it is oxidized beyond the acetic acid state to carbon dioxide and water.

Methods based on these principles have been employed for the determination of alcohol in blood,<sup>11-17</sup> urine,<sup>11-17</sup> saliva,<sup>11-15, 18, 19</sup> spinal fluid,<sup>20</sup> and the breath.<sup>21, 22</sup> Practical considerations and preferences of workers in the field have limited the specimens obtained from living subjects to the breath and urine, except that when a physician is available and the subject's consent is given blood samples may also be obtained. Saliva and the spinal fluid never seem to have enjoyed any popularity. Harger<sup>23</sup> believes that saliva should be used much more than it is.



**Fig. 196(c). The Alcometer. (Courtesy, Alfred Bicknell Associates.)**

### **Field Tests**

By using portable equipment, chemical tests for alcohol can be made at the scene of the accident. Two methods that employ the breath as the source of body alcohol are available for field tests. The "Alcoholometer" (or Alcometer as it is now called) developed by Greenberg and Keator<sup>24</sup> is completely automatic and may be operated by untrained personnel while the "Drunkometer" o



Harger<sup>25</sup> is simple enough to be used by most police officers, although some special training is required (Fig. 196).

The operation of either apparatus should offer no difficulty to laboratory personnel. A knowledge of the use of the analytical balance and standardization of solutions is necessary, however.

### Laboratory Tests

Tests for alcohol in body fluids are performed in the laboratory under the following circumstances:

When no field tests were made at the time of the accident but samples were obtained for analysis

When confirmation of the results of the field tests is thought to be desirable

When the person to be examined died before the field tests were made

When criticism of nonspecificity<sup>26</sup> of the methods commonly employed is likely to be raised, the method of Kozelka and Hine (v.i.) may be used. These investigators have shown that in their method interfering substances are removed quantitatively. It is not necessary then to make any tests for the presence of certain medicines or other alleged contaminants which might vitiate the results.

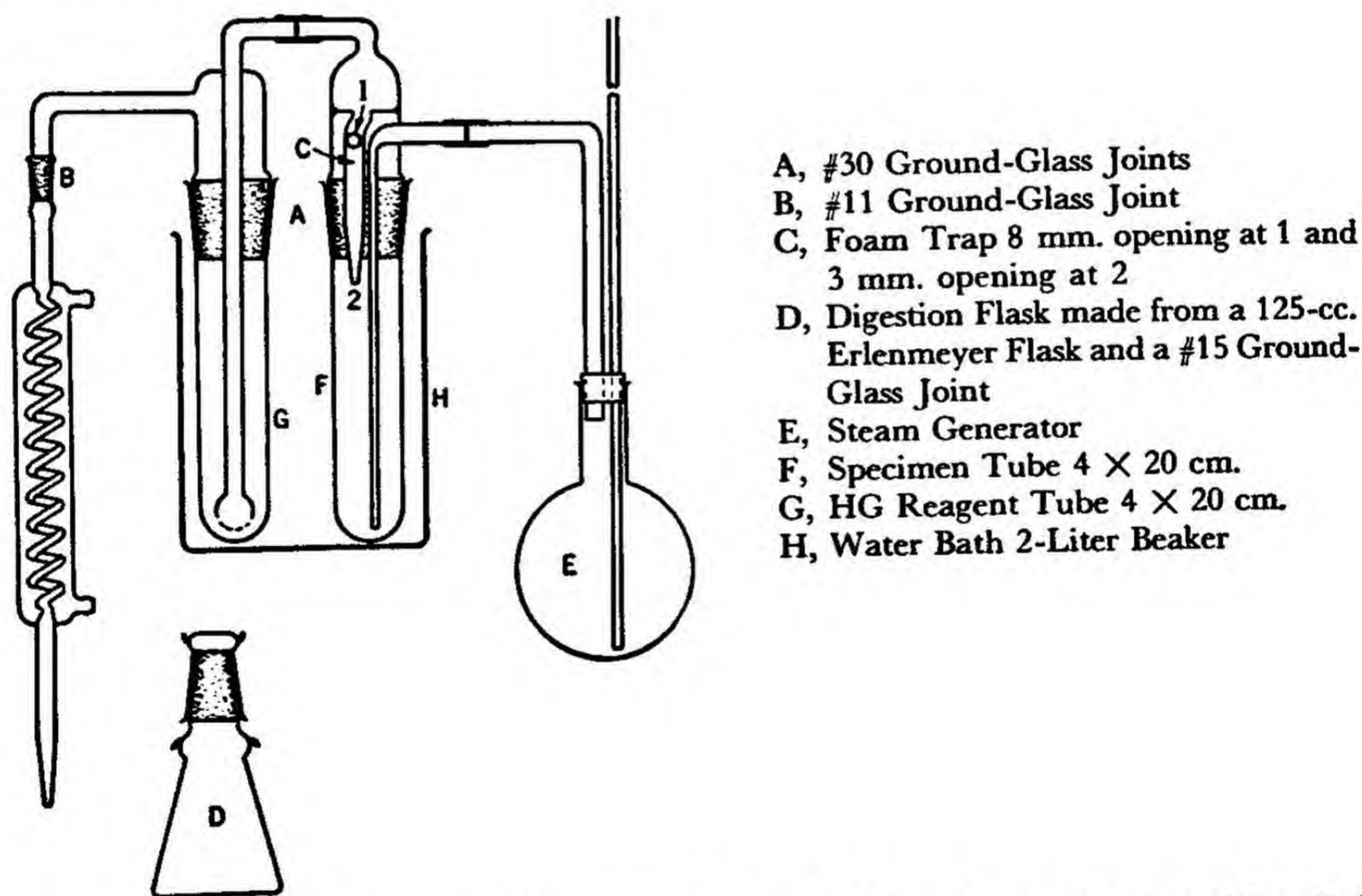


Fig. 197. Distillation apparatus. (Courtesy, F. L. Kozelka and the American Chemical Society.)

### Method of Kozelka and Hine

"The distillation apparatus and digestion flask are shown in Figure 197. The two tubes *F* and *G*, are held in place during the distillation by springs attached to the top of the tubes and the side arms. The foam trap, *C*, as constructed will prevent the me-



chanical carrying over of material, even when considerable foaming occurs. The vapor passes through the opening at 1, and the condensate, together with any fluid forced through the opening, returns to the distillation tube through the opening at 2. The alcohol is collected from the condenser in flask *D*.

"The male portion of the joint of tube *G* must be covered with graphite to prevent sticking. The graphite is best applied by using a carpenter's pencil, although an ordinary pencil will serve the purpose.

"A 2-liter beaker may be used for the boiling water bath, *H*. The digestion flask, *D*, is constructed from a 125-cc. Erlenmeyer flask and a No. 15 interchangeable ground-glass joint. The cap is kept in place with two coil springs, 0.6 cm. (0.25 in.) in diameter, made from 20-gauge spring-steel wire. Considerable tension must be maintained on the springs to prevent the cap from being raised by the vapor pressure and breaking the cap or the flask when it snaps back into position. Two 10-cc. all-automatic burets are most convenient for the 0.1 *N* potassium dichromate and 0.1 *N* sodium thiosulfate solutions.

### REAGENTS

"Potassium dichromate solution, 0.1 *N*, 4.903 grams per liter, reagent quality. A solution prepared from reagent quality potassium dichromate agrees with the theoretical yield of alcohol by direct digestion of standard alcohol solutions. One cubic centimeter of the solution is equivalent to 1.15 mg of alcohol, (A 0.1 *N* solution is preferred to more dilute solutions because it covers the range of the quantities of alcohol commonly found in the blood or urine specimens, and if reasonable care is exercised excellent checks can be obtained even with as small quantities as 0.005 per cent.)

"Sodium thiosulfate solution, 0.1 *N*, 25 grams of sodium thiosulfate plus 0.1 gram of sodium bicarbonate per liter. This solution is standardized against the 0.1 *N* potassium dichromate solution.

"Potassium iodide crystals, analytical reagent, must be free from iodates.

"Arrowroot starch, 1 per cent solution. (A fresh solution must be used).

"Sulfuric acid, concentrated, reagent quality.

"Mercuric chloride, saturated aqueous solution.

"Sodium hydroxide, saturated solution.

"Sodium tungstate, 10 per cent solution.

"Sulfuric acid, 1 *N* solution.

### PROCEDURE

"The blood or urine specimen (1 or 2 cc.) is measured into the distillation tube, *F*, and the protein is precipitated by the addition of 5 cc. of 10 per cent sodium tungstate and 5 cc. of 1 *N* sulfuric acid. These quantities of tungstate and sulfuric acid for a 2-cc. blood specimen effect a complete precipitation of the proteins, and little, if any, foaming occurs during the distillation. Since urine specimens do not ordinarily contain protein, it is usually unnecessary to add the tungstate. The analyses can be made on coagulated blood; however, care must be exercised when taking a sample for the determination to obtain proportionate amounts of the serum and clot. Whenever possible, an anticoagulant, such as sodium citrate, oxalate or fluoride, should be employed.

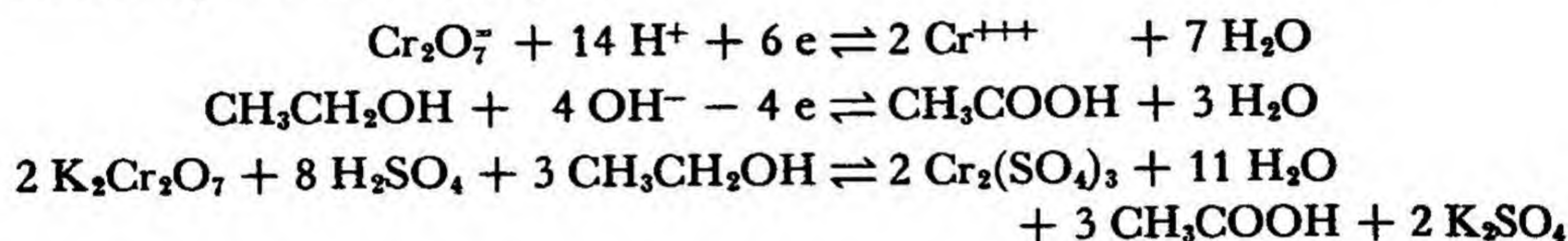
"Ten cubic centimeters of a saturated solution of mercuric chloride and 10 cc. of a saturated solution of sodium hydroxide are measured into tube *G*. The tubes are then connected to the distillation apparatus and immersed in the hot water bath, which



should be kept at the boiling temperature during the distillation process. The alcohol is steam-distilled directly into the digestion flask, *D*. After 25 to 30 cc. are distilled, 10 cc. of the 0.1 *N* potassium dichromate solution and 5 cc. of concentrated sulfuric acid are added to the distillate. The sulfuric acid should be allowed to run down the side of the flask to prevent it from mixing with the aqueous solution and causing the heat of solution to raise the temperature before the flask is closed. After the flask is closed and the cap fastened with the two springs, the solution is mixed. The flask is then placed in a boiling water bath for 20 minutes. The solution is cooled, and the dichromate solution is washed down the sides of the flask with a stream of water from a wash bottle. Enough water should be added to dilute the acid to a 10 per cent solution or less. The excess dichromate is determined by adding approximately 0.2 gram of potassium iodide crystals and titrating the liberated iodine with the standardized solution of 0.1 *N* solution sodium thiosulfate. Addition of the starch indicator should be delayed until the iodine color is nearly removed. Five drops of the 1 per cent starch solution are then added and the titration is completed."<sup>7</sup>\*

### Calculations

The chemistry of the reaction employed in the above method may be described by the following equations:



It follows, therefore, that the equivalent weight of potassium dichromate is  $\frac{1}{6}$  the molecular weight or 49.04 g, and a 0.1 *N* solution would contain 4.904 grams per liter of solution. The equivalent weight of ethyl alcohol is  $\frac{1}{4}$  the molecular weight or 11.51 g.

The quantity of alcohol present in the sample and the per cent blood alcohol are calculated by substitution in the following equations:

$$[(V_d)(N_d) - (V_t)(N_t)] \times \frac{11.51}{V_s} = \text{mg of alcohol per ml of sample,}$$

where

$V_d$  = volume in ml of dichromate solution used

$N_d$  = normality of dichromate solution

$V_t$  = volume in ml of thiosulfate solution used

$N_t$  = normality of thiosulfate solution

$V_s$  = volume in ml of sample of blood or urine.

If a 1-ml sample of blood or urine is used and both the dichromate and thiosulfate are exactly 0.1 *N*, this expression may be simplified to:

$$(10 - V_t) \times 1.15 = \text{mg of alcohol per ml of sample.}$$

\* F. L. Kozelka and C. H. Hine, "Method for Determination of Ethyl Alcohol for Medical Purposes," *Ind. Eng. Chem., Anal. Ed.*, 13, 905-907 (1941), copyrighted 1941 by the American Chemical Society.



Milligrams of alcohol per milliliter of sample are converted into blood alcohol per cent as follows:

Blood samples: By definition,

$$\frac{\text{mg of alcohol per ml of sample}}{10} = \text{blood alcohol per cent}$$

Urine samples:

$$\frac{\text{mg of alcohol per ml of sample}}{13} = \text{blood alcohol per cent}$$

The factor 13 is based upon the fact that alcohol is distributed in the body in proportion to the water content. Urine has a greater water content than blood, the distribution of alcohol, therefore, being greater (1.3 times) in urine than in blood, i.e., blood alcohol  $\times 1.3$  = urine alcohol.

As an example, let it be supposed that 10.00 ml of a 0.1042 *N* dichromate solution were digested for 20 minutes with the distillate of a 2.00 ml sample of urine. On back titration, 7.86 ml of a 0.0996 *N* thiosulfate solution were required. What is the per cent blood alcohol?

$$[(10)(0.1042) - (7.86)(0.0996)] \times \frac{11.51}{2} = 1.49 \text{ mg of alcohol per ml of sample}$$

$$\frac{1.49}{13} = 0.11 \text{ per cent blood alcohol}$$

### 3. SAMPLING

It has been remarked that the results of a scientific examination can be no better than the sample which was obtained for analysis. If an adequate, representative, uncontaminated sample is obtained, properly marked for identification, sealed against tampering, and if an accepted method of analysis is used, the results are not open to serious challenge. This is particularly true in regard to samples of body fluids obtained for alcoholic analysis. In these cases special precautions are necessary. For example, sterilization of the skin with alcohol must be avoided when taking blood specimens. If the person is dead, the body fluid must be taken before any embalming fluid is used. Of the many preservatives available sodium fluoride is satisfactory and may be employed to prevent coagulation of blood, in addition to preserving blood, urine, or other fluid from bacterial action. It is advisable, therefore, that a few recommendations be made relative to the problem of sampling, even though consideration has been given to the general problem of obtaining evidence in Chapter. 4.

The following suggestions are made by the National Safety Council:

"Obtain specimens as soon as possible after the accident or violation. If equipment is available, a preliminary breath test can be run at the scene of the accident or violation, or at designated places such as hospitals or police stations. Wait at least 15 minutes before obtaining the breath specimen, to be sure that possible recent drinking will not affect the test."



"Saliva may be obtained at the scene of the accident or violation, waiting at least ten minutes after the time of the accident before attempting to obtain the sample. Then have the suspect rinse his mouth thoroughly several times, and wait at least five minutes more. Then have the subject chew *paraffin* and discard first part of flow of saliva. (Do not permit chewing gum to be substituted for the *paraffin*.)

"The person taking specimens of urine, saliva or breath should see the defendant give it, but hands should not be laid upon the accused person in order to obtain the specimen.

"Blood specimens should be taken only by a physician, medical technologist, or other person with similar qualifications. They should be taken with the consent of the accused person, unless he is in an unconscious condition. When taking the specimen, the skin and the instruments must not be disinfected with alcohol, ether, or other volatile reducing organic fluid. Use a 1:1000 bichloride of mercury solution.

"Each body fluid specimen should be placed in at least two separate containers, and sealed and labeled in the presence of witnesses and the suspected person. One of the sealed specimens should be reserved for use by the defense in case there is a request for an analysis in another laboratory. The amount of fluid to be obtained will depend upon the procedure used in chemical analysis, but there should be enough for at least three tests.

"In important cases, obtain specimens of two different body materials or obtain an additional specimen of the same material at a later time to provide evidence for a more convincing case.

"Each specimen obtained should immediately be tightly stoppered and sealed with gummed paper in the presence of witnesses. The label should show an identification number, the date and time the specimen was obtained, and the signature of the person taking the specimen.

"The person who supervised the taking of the specimens should deliver them personally to the chemist, technologist or physician who is to analyze them. If sent by mail, he should send them special delivery, registered mail.

"If the specimen is to be stored, it should be kept under lock and key in a cool place. If considerable time is to elapse between the taking of the specimen and its analysis, proper preservative material should be in the containers."<sup>28\*</sup>

### Preserving Specimens

A quantity of 10 mg of sodium fluoride per ml of blood, urine, or saliva (or 5 grains per fl oz) is sufficient to preserve the specimen for a week at room temperature. If the specimen is to be preserved indefinitely, a larger quantity of fluoride (100 mg per ml of sample) is required and the sample should be kept in a refrigerator.

It is advisable that a portion of the specimen be retained in a tightly stoppered, sealed container, and kept in a refrigerator until the case is closed in order to give the defense an opportunity to make a check test if they so desire.

Haggard, *et al.*<sup>29</sup> have studied the problem of urine sampling. These investigators have shown that between one and one-half hours and ten hours after the

\* Committee on Tests for Intoxication, *Annual Report to Street and Highway Traffic Section, National Safety Council, Chicago, 1938*, pp. 21-22; National Safety Council *Public Safety Memo No. 29, July 1947*, pp. 6-7.



consumption of alcohol the urine may be used to determine the concentration of alcohol in the blood. Special precautions, however, are required in obtaining the urine samples. The procedure recommended is as follows:

Request the subject to empty his bladder. Discard this sample. One-half hour later again request the subject to void his bladder. This sample is used for the determination. After another half-hour collect another sample. This is also examined for alcoholic content.

Each sample of blood (or saliva) should total at least 10 ml. A greater quantity of urine may be collected, although 10 ml are sufficient. The samples are collected in wide-mouthed bottles and closed tightly with rubber stoppers. A 1-oz size bottle containing about 5 grains (300 mg) of sodium fluoride is satisfactory for samples of blood or saliva. A 4- or 6-oz size bottle may be used for urine samples; about 20–30 grains (2 g) of sodium fluoride are added to each bottle in this case.

If more than one laboratory is to examine the specimen, a duplicate set of samples must be obtained. Do not discard any specimens until the case has been disposed of in court. Storage of the specimen in a refrigerator will assist in its preservation.

#### 4. FORENSIC CONSIDERATIONS

In order that the significance of the chemical tests may be fully appreciated by the court and jury, especially in communities where no relevant laws have been enacted by the legislature, it may become necessary for the expert to explain the effect of alcohol on man in terms of the concentration found in the blood (or other body fluid). The expert must have an adequate background of clinical observations and experimental work on which he is able to base the correlation between the degree of impairment of the mental and physical faculties and the concentration of alcohol found in the blood. In addition, he must be thoroughly acquainted with the literature of the subject, particularly that of the physiology of alcohol and tolerance.

##### **The Physiology of Alcohol** <sup>30, 31</sup>

Alcohol is rapidly absorbed in the small intestines and to a lesser extent in the stomach. It is carried by the blood stream to all parts of the body. It is possible, therefore, within a relatively short time after ingestion, to detect alcohol in all organs, fluids, and tissues, where it is distributed uniformly and in approximately the same proportion as the water content of that part.

Alcohol is eliminated from the body by oxidation and excretion. Oxidation takes place in the liver. This organ is responsible for the elimination of 90 to 99 per cent of the alcohol ingested. Excretion takes place mainly through the kidneys (urine) and lungs (breath). About 2 per cent of the alcohol is eliminated in this fashion but in some cases as high as 10 per cent may be excreted.

Estimates for the elimination of alcohol vary. Values ranging from approximately 1 oz in 8 hours<sup>32</sup> to approximately 1 oz in 3 hours<sup>33</sup> have been reported.



Haggard and Greenberg<sup>34</sup> claim that during each hour the body oxidizes about one-sixth of the remaining absorbed alcohol.

### Tolerance<sup>35, 36, 37</sup>

It is common experience that the intoxicating effects produced by alcoholic beverages vary from individual to individual; even with the same person, variations in the effects of alcohol are experienced at different times.

This phenomenon of different resistances to alcohol is sometimes used in an attempt to discredit the reliability and validity of the results of the chemical tests of body substances for alcohol. In order to meet this objection, it is necessary to know the current theories concerning the phenomenon of *alcohol tolerance*. This subject is, as yet, not completely understood.

Muehlberger<sup>38</sup> in a critical review of the literature points out that there are two aspects of tolerance:

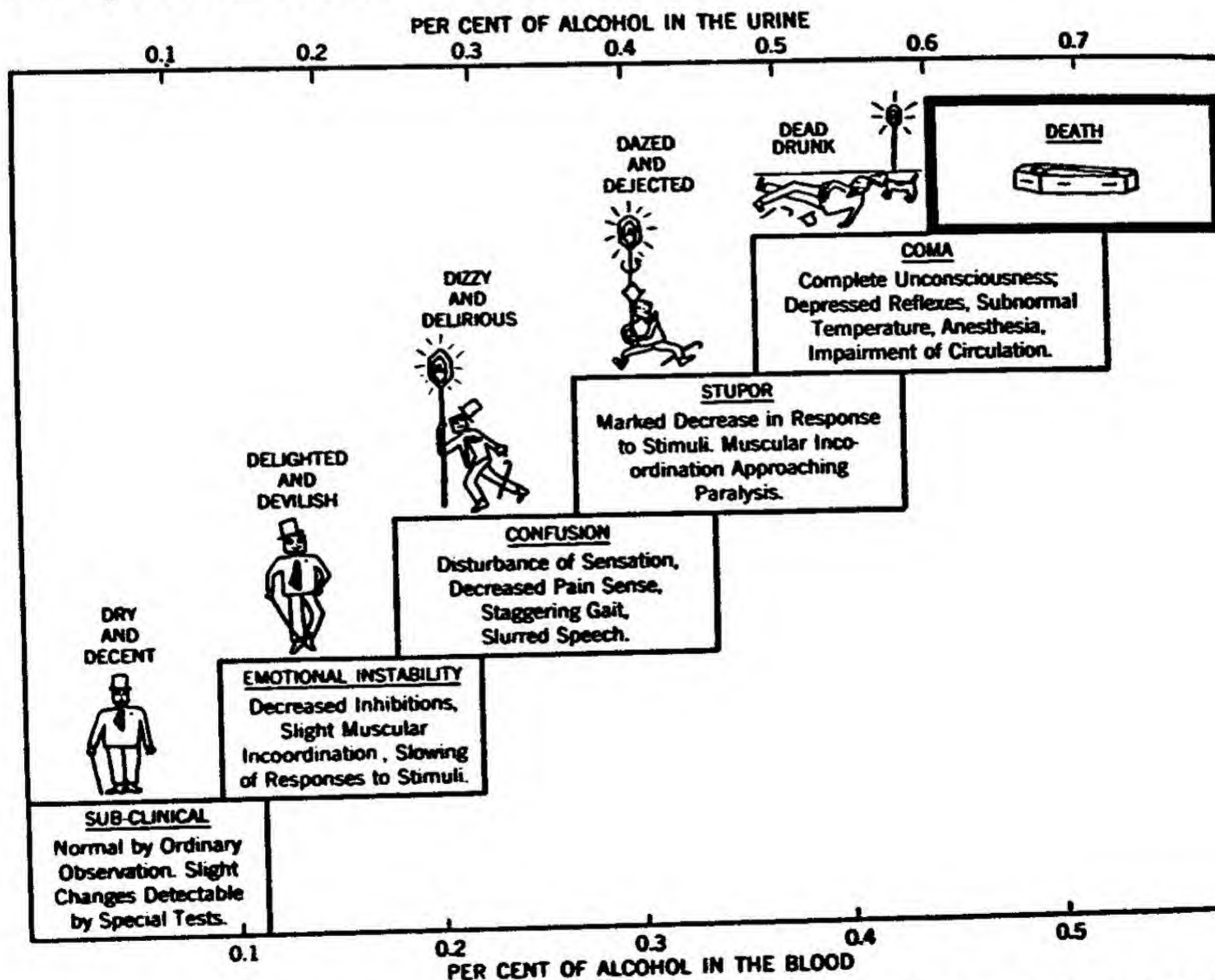


Fig. 198. Relation between concentration of alcohol in the blood or urine to behavior while "under the influence." (Courtesy, C. W. Muehlberger.)

*Consumption tolerance*, which may be natural but in most cases is acquired through repeated drinking, is an expression used to describe the fact that different persons must drink different amounts of an alcoholic liquid to produce the same concentration of alcohol in the blood. Thus a tolerant individual after taking the same number of drinks has a lower concentration of alcohol in his



blood than a person whose consumption tolerance is not great. The reasons for this are not clearly understood at present.

*Constitutional or "tissue" tolerance* is an expression used to indicate that the degree of intoxication is a function of the concentration of alcohol in the blood. In other words, individuals are affected to about the same degree at the same blood alcohol level, regardless of the total amount of alcohol drunk or their consumption tolerance. Since constitutional or tissue tolerance is about the same for each person and since the chemical tests of blood (and other body substances) measure the concentration of alcohol present, the validity of their use as an index of intoxication is not open to serious challenge. However, to forestall any possible criticisms two limits, as we have seen, were sanctioned. Blood alcohol values below the lower limit are *prima facie* evidence of sobriety while those above the upper limit are *prima facie* evidence that, insofar as the operation of an automobile is concerned, a person is under the influence of alcohol sufficiently to impair his driving ability. Values between the two limits establish that alcohol is present in the system but are not conclusive evidence of a person's being under its influence.

Closely associated with the problem of sampling (sec. 3) is the question of compulsion and constitutionality. An elaborate treatment of this subject may be found in an article by Ladd and Gibson.<sup>39</sup> More recently, Mamet<sup>40</sup> has published a paper which also discusses this topic. These writers feel optimistic about the ultimate outcome of the legal controversy which revolves around the questions of compulsion, self-incrimination, and constitutionality in connection with the use of these tests and the presentation of the results as evidence in court.

## EXERCISES

1. Prepare a solution of approximately 1 per cent by volume of ethyl alcohol in water. Ascertain its concentration in mg per ml accurately by determining its specific gravity or refractive index. This solution is to be used in exercise 3.

2. Obtain a sample of urine from a person who has not indulged in any alcoholic beverage for the preceding 24–48 hours. Add one-half a teaspoon of sodium fluoride as a preservative to every 6 oz (180 ml) of sample. This sample is to be used in exercise 3.

Use 1 to 2 ml of this urine for a blank determination. Follow the directions given for the method of Kozelka and Hine. Make two additional blank determinations.

3. To 100 ml of urine obtained for exercise 2, add 5 ml of the alcohol solution prepared in exercise 1. Thoroughly mix the two solutions. Determine the concentration of alcohol following the method of Kozelka and Hine. Check the results obtained with the known concentration as calculated from the data of exercise 1. Repeat the experiment three times or until good accuracy is obtained. It has been recommended that analysts who are to perform these tests for court use should have "had experience in running at least 50 specimens with known quantities of alcohol."<sup>41</sup> To convert mg per ml of alcohol in urine to per cent blood alcohol divide the urine alcohol value by 13.

4. Have a subject drink about 250–300 ml of whiskey, i.e., 8–10 oz in 4 or 5 high-balls; one-and-a-half hours after the last drink, have the subject empty his bladder. A half-hour later collect a sample of his urine. Analyze this for its alcoholic content. After



another half-hour collect another urine sample and analyze this for its alcoholic content. At least three analyses must be made of each sample.

At the time of taking each sample, write down your observations concerning any signs of intoxication. Correlate your observations with the per cent blood alcohol found to be present at the time the sample was obtained.

Continue to obtain samples of urine every hour for ten hours or until no alcohol appears in the urine. Analyze these samples in duplicate.

5. Repeat exercise 4 on another day using only 60 ml of whiskey, i.e., 2 oz in one highball.

6. Repeat exercise 4 on another day using 350–400 ml of whiskey, i.e., 12–14 oz of whiskey in 6 or 7 highballs.

7. Repeat exercise 4 using 250 ml of gin instead of whiskey.

8. Repeat exercise 4 using a quart of wine.

9. Repeat exercise 4 using 6 to 8 large bottles of beer as the source of the alcohol. This experiment should be conducted for at least ten hours, obtaining samples of urine every half-hour or hour for analysis.

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# CHAPTER 27

## LIQUOR ANALYSIS

Many states have legislation to control the manufacture, distribution, and sale of liquors, wines, beers, whiskeys, and other alcoholic beverages; others continue to prohibit their sale entirely, except for medicinal purposes. Thus, when an arrest is made for a violation of the state liquor law, it is necessary to have the liquor analyzed. This analysis determines the nature and percentage of the alcohol in the liquid and establishes that it can be consumed by a human being.

Usually, the defendant does not challenge the fact that the liquid was suitable for drinking purposes, since, in most cases, this would enable the arresting officer to bring an additional and more serious charge against him. Occasionally, however, the arresting officer is especially interested in finding out if the evidence was unfit for human consumption. This situation might arise in connection with an investigation of a complaint that an alcoholic beverage from a particular source was responsible for a person's illness or death. Unscrupulous individuals have occasionally sold wood (methyl) alcohol or mixed it with grain (ethyl) alcohol for drinking purposes when the high profit to be realized made such a risky undertaking seem worth while. Since the sale of wood alcohol for beverage purposes is specifically prohibited under the law, a chemical analysis is necessary to establish its presence in the suspected evidence.

### 1. DETERMINATION OF PERCENTAGE OF ALCOHOL

The determination of the percentage of alcohol in a sample of an alcoholic beverage is based upon the fact that variations in the percentage composition of aqueous ethyl alcohol solutions are accompanied by variations in the physical properties of the solution. Thus the amount of alcohol in a water solution may be determined by physical methods which measure either index of refraction or specific gravity. Tables which list percentage of alcohol in terms of these physical constants have been carefully worked out and have been reproduced in several texts.<sup>1-6</sup>

It is easier to determine the refractive index accurately than the specific gravity. The dipping refractometer (Chap. 40) is a convenient instrument for this purpose. Specific gravity may be determined roughly by means of a hy-



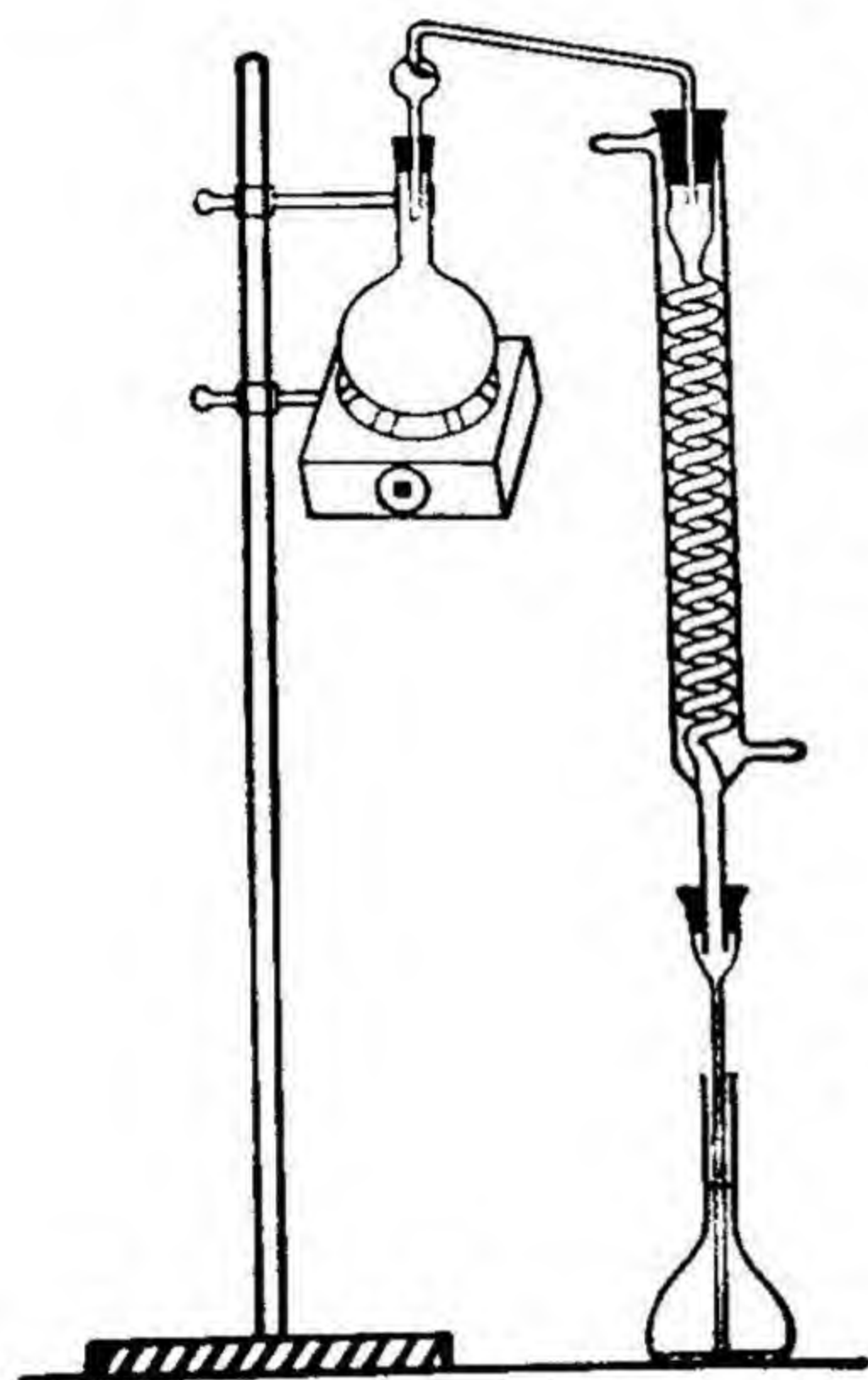
drometer but for accurate work the Westphal balance or pycnometer (Chap. 7) is required.

Accurate and uniform results in these determinations are dependent upon the removal of all compounds (other than the alcohol and water) that may be present in the sample when it is submitted for analysis by the arresting officer. This may be accomplished by the distillation of a portion of the sample. The distillate, then, is the liquid of which the refractive index or specific gravity is measured.

### Procedure for Distillation

The distilling apparatus is assembled as shown in Fig. 199. A few boiling stones (chips of clay plate or small pieces of glass tubing) are dropped into the distilling flask to prevent superheating and bumping of the liquid.

If the sample submitted is whiskey or other liquor which is thought to contain more than 25 per cent alcohol, add exactly 25 ml of sample to the distilling flask. Rinse the volumetric flask or pipette used to measure the sample twice with about 15 ml of water each time, and add these washings to the distilling flask. The contents of the flask are then diluted with 100 ml of water. If the sample is wine, beer, or other beverage with an alcoholic content below 25 per cent, increase the amount of sample used to exactly 100 ml and wash the volumetric flask twice with 50 ml of water each time. No further dilution is necessary.



**Fig. 199. Apparatus used in the distillation of alcohol.**

Test the acidity of this mixture with blue litmus paper. If acid, add a dilute solution of sodium hydroxide until it is alkaline. The purpose of this is to neutralize volatile acids, such as acetic, which might be present as a result of fermentation. For most samples this will be unnecessary.

The sample is now ready to be distilled. Heat is applied gradually to the distilling flask until the solution starts to boil. The distillation is continued at a steady rate (a drop every few seconds) until almost 100 ml have been recovered. The volumetric flask is then made up to volume by adding water from a wash bottle until the bottom of the meniscus is tangent to the ring etched on the neck of the flask. The percentage of alcohol in the distillate is then determined. With whiskey and other liquors of high alcoholic content where a 25 ml sample was used, the percentage of alcohol in the 100 ml distillate is multiplied by 4 to obtain the content of the original sample.

If the sample submitted is less than 25 ml (or 100 ml) a smaller volume may be used. The principle is the same — a known volume of a sample is distilled, and the distillate is collected and made up to the original volume with distilled water.



## 2. THE IODOFORM TEST

The determination of percentage alcohol from physical measurements is based on the assumption that the distillate is composed of ethyl alcohol and water. It is advisable then that a chemical test also be made to establish the presence of ethyl alcohol. The test used for this purpose is the iodoform reaction.

### Directions

To 5 ml of the distillate add 0.5 to 1.0 ml of a 10 per cent sodium hydroxide solution, and to this add dropwise an iodine-potassium iodide solution\* until a slight excess yields a definite, dark color of iodine. If no precipitate forms immediately, allow the solution to stand for several minutes, then shake and notice if any iodoform has precipitated. Smell the solution for the characteristic odor of iodoform. If no iodoform precipitates in the cold, heat the solution to 60 C for a minute and set aside until cool. The presence of ethyl alcohol is shown by the gradual precipitation of a yellowish, crystalline compound, with the odor characteristic of iodoform. If necessary, these crystals may be identified by observation of their characteristic structure with a microscope (medium-power).

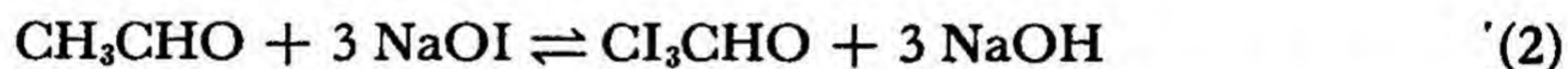
### Specificity

The iodoform reaction takes place in three steps:

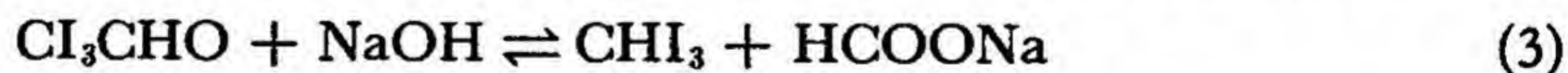
Oxidation of the ethyl alcohol to acetaldehyde by sodium hypoiodite  
( $2 \text{ NaOH} + \text{I}_2 \longrightarrow \text{NaOI} + \text{NaI} + \text{H}_2\text{O}$ )



Iodination of acetaldehyde



Hydrolysis of the iodinated aldehyde, with the formation of iodoform



The iodoform reaction is not specific for ethyl alcohol because a few other compounds react similarly. Methyl alcohol, however, does not form iodoform so that this test differentiates between these alcohols. For practical purposes, then, a positive iodoform reaction is sufficient identification for ethyl alcohol in alcoholic beverages.

## 3. MIXTURES OF ETHYL AND METHYL ALCOHOL

The substitution of methyl alcohol or other alcohol which is less expensive than pure ethyl alcohol is sometimes made when the alcohol is to be used in flavoring extracts, perfumes, cosmetics, etc. It is sometimes done even when the

\* This solution is prepared by dissolving 20 g of potassium iodide in 20 to 30 ml of distilled water, adding 10 g of iodine crystals, and stirring until solution is complete. Sufficient distilled water is then added to make a final volume of 80 ml.



alcohol is to be used for beverage purposes. Consequently, the laboratory may be called upon occasionally to make quantitative measurements of the amounts of methyl and ethyl alcohol in a sample.

### Method of Determination<sup>7</sup>

The specific gravities of pure methyl and pure ethyl alcohol differ by little, but their indices of refraction differ considerably. Thus, the percentage by weight of alcohol, i.e., total alcohol (ethyl and methyl), in the distillate is determined in the usual manner using the pycnometer method and the same specific gravity tables\* as for pure ethyl alcohol-water solutions.<sup>1-6</sup> The scale reading at 20 C of the Zeiss† immersion refractometer is obtained in the usual manner for the mixture. A table which lists the scale readings corresponding to pure methyl alcohol-water solutions from 0 to 100 per cent is available.<sup>7-10</sup> The same table also gives similar information for pure ethyl alcohol-water solutions. The percentage of methyl and ethyl alcohol mixtures in water solution is determined by interpolation. The following example will illustrate the method of calculation:

Assume that the percentage alcohol (methyl and ethyl) in the distillate was found to be 24.75 per cent by weight using the specific gravity (pycnometer) method. The scale reading of the immersion refractometer for the distillate was 43.2 (20 C).

From the table mentioned above it is possible to obtain by interpolation the refractometer scale readings corresponding to (24.75 per cent) methyl alcohol-water and (24.75 per cent) ethyl alcohol-water mixtures. The table shows that a solution of 24 per cent methyl alcohol in water has an immersion refractometer scale reading of 29.1; for ethyl alcohol the scale reading is 58.2 (20 C). A 25 per cent methyl alcohol solution has a scale reading of 29.7 and for ethyl alcohol the reading is 60.1. Thus:

<i>Per cent methyl alcohol</i>	<i>Refractometer scale reading</i>
24	29.1
(24.75)	(x)
25	29.7
<i>Per cent ethyl alcohol</i>	<i>Refractometer scale reading</i>
24	58.2
(24.75)	(y)
25	60.1

By interpolation,

$$x = 29.6 \quad \text{and} \quad y = 59.6$$

Therefore the immersion refractometer scale reading corresponding to 24.75 per cent methyl alcohol in water would be 29.6; the scale reading for

\* While traditionally the  $\frac{20 \text{ C}}{4 \text{ C}}$  table is used, the  $\frac{15.56 \text{ C}}{15.56 \text{ C}}$  table should be used for more accurate results.

† Immersion refractometers of other manufacturers may also be used provided their readings are those of the arbitrary scale suggested by Pulfrich.



24.75 per cent ethyl alcohol in water would be 59.6. The scale reading of the mixture of methyl and ethyl alcohol in the distillate was found experimentally to be 43.2. The percentage of each alcohol is found as follows:

<i>Per cent Alcohol</i>		<i>Refractometer scale reading</i>
ethyl	24.75	59.6
mixture	24.75	43.2
methyl	24.75	29.6

The percentage of ethyl alcohol is found by interpolation. Thus:

$$\begin{array}{r}
 43.2 \\
 29.6 \\
 \hline
 13.6
 \end{array}
 \qquad
 \begin{array}{r}
 59.6 \\
 29.6 \\
 \hline
 30.00
 \end{array}$$

$$\frac{13.6}{30.0} \times 100 = 45.3 \text{ per cent}$$

Hence, 45.3 per cent of the alcohol present is ethyl alcohol, and 54.7 per cent is methyl alcohol.

When the percentage of methyl alcohol is determined to be less than 2 per cent in solutions of small total (10 per cent) alcoholic content or less than 0.5 per cent in solutions of high total (50 per cent) alcoholic content, it is advisable that its presence be confirmed by qualitative chemical tests.

Beyer and Reeves<sup>11</sup> have also investigated the use of the Zeiss immersion refractometer as a means of determining methanol and ethanol in mixtures of the two alcohols in aqueous solution. These investigators have improved on Leach and Lythgoe's data<sup>12</sup> and have suggested an empirical method of calculation which yields results that are more accurate.

Other alcohols also have been used as adulterants or substitutes for ethyl alcohol in flavorings and extracts, as well as in tinctures, liniments, and other medicinal preparations which contain alcohol as the solvent. The authors are familiar with a case in which isopropyl alcohol was fraudulently substituted for ethyl alcohol in colognes and other toilet preparations.

In these cases the specific gravities of ethyl and isopropyl alcohol (or higher alcohols) are not sufficiently close to use the above method in the estimation of *total* alcohol present. It is necessary therefore to do this indirectly by first determining the amount of water present in the distillate of the sample. This may be done by using calcium carbide and estimating the quantity of acetylene evolved.<sup>13</sup> The water content may also be determined by titration with the Karl Fischer reagent. Zerban and Sattler<sup>14</sup> have described a method in which specially designed apparatus facilitates the titration by minimizing the manipulative difficulties arising from the experimental conditions required for the use of the reagent.

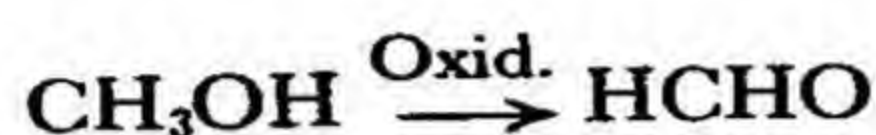
Knowing the percentage of water, the relative percentages of ethyl and isopropyl (or higher) alcohol may be determined by measurement of the refractive index of the solution. If no table exists in which refractometer scale readings *vs.* percentage alcohol (isopropyl<sup>15</sup> or higher alcohol) are given, it will be necessary to construct a table by experimentation.



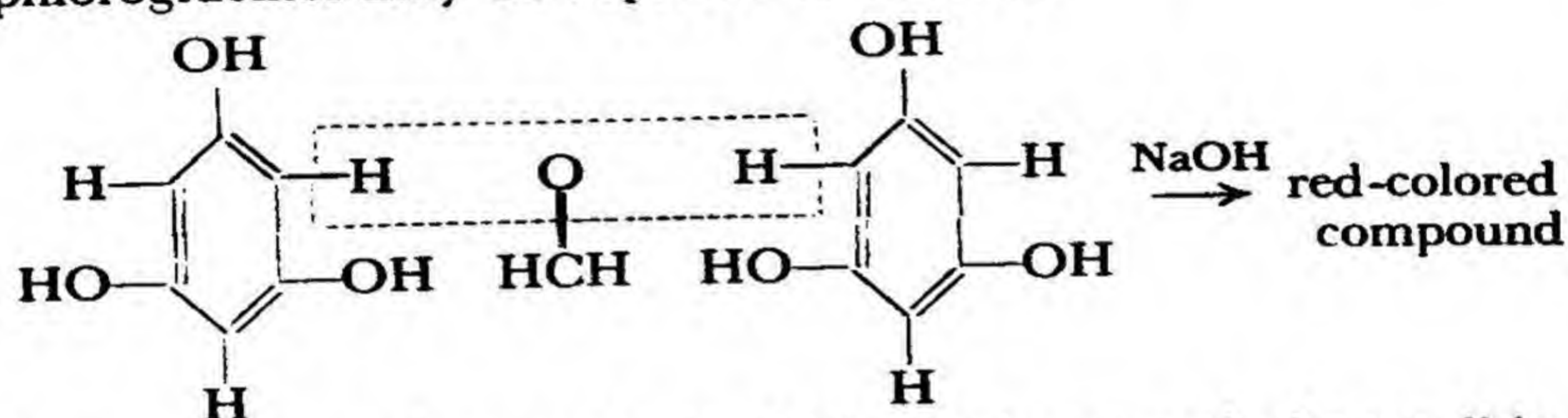
#### 4. OTHER CONSTITUENTS

Several constituents or possible contaminants and adulterants which might be found in alcoholic beverages are mentioned below. Examinations for these compounds are not made frequently in police laboratories so that stepwise directions, which are available elsewhere<sup>16, 17</sup> will not be given. The nature of the reactions, however, will be mentioned so that if it becomes necessary to perform any of these tests or to answer questions concerning them in court, the investigator will be fortified with the necessary theoretical knowledge.

*Methyl Alcohol* — The methods used to detect methyl alcohol depend on its oxidation (by a hot spiral of copper wire or chemical oxidizing agent such as  $\text{KMnO}_4$ ) to formaldehyde and the detection of the latter compound.

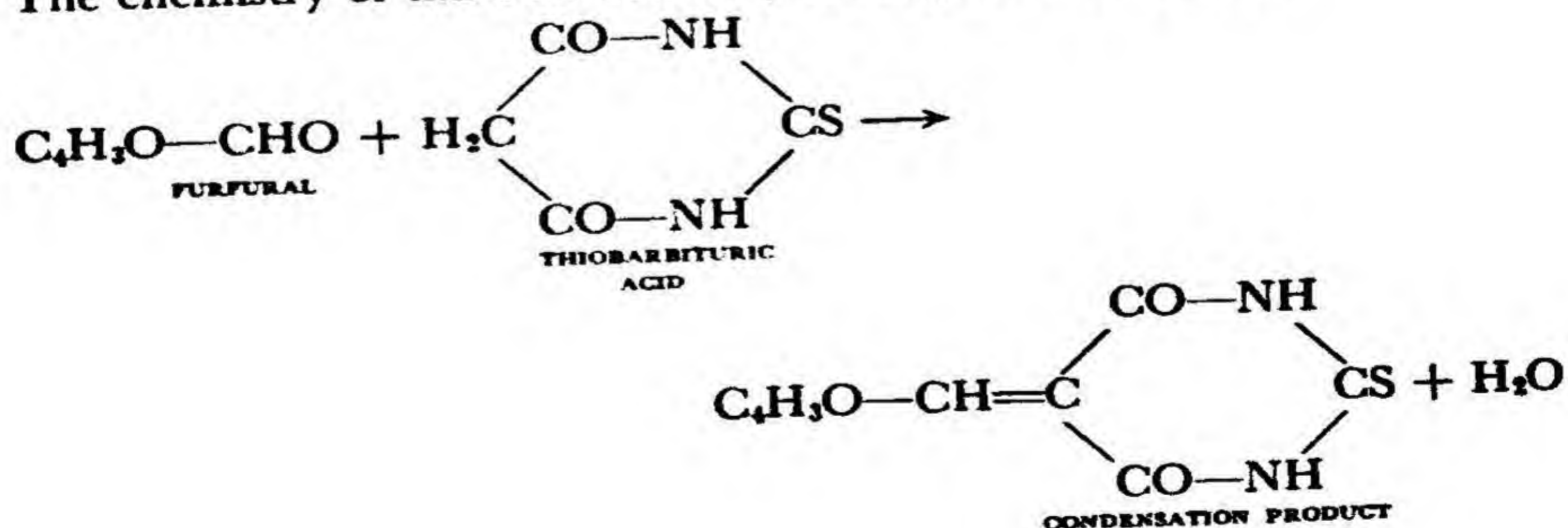


*Formaldehyde* — This is detected by Schiff's fuchsin-sulfurous acid reagent or by a polyphenol in alkaline solution. For example, the condensation with phloroglucinol may be depicted as follows:



Since these reactions apply to aldehydes in general, the conditions must be controlled to eliminate any positive reaction which would result from any acetaldehyde that may be formed during the oxidation of the methyl alcohol. If the test for aldehydes is made directly on the original sample or the distillate, no special precautions need be taken.

*Furfural* — This aldehyde does not give a satisfactory test with Schiff's reagent but does condense with polyphenols and other aromatic compounds containing ortho and para activated hydrogens. Thus aniline hydrochloride condenses with furfural to give a violet color. With thiobarbituric acid<sup>18</sup> furfural forms a flocculent lemonish-yellow precipitate. The chemistry of this reaction may be depicted as follows:





*Acetone* — This compound (and other compounds such as isopropyl alcohol that can be oxidized to acetone) is detected by mercuric sulfate solution, which forms an insoluble precipitate with acetone.

*Coloring Matter of Whiskey* — By extraction of the original whiskey sample with an immiscible solvent such as acidified amyl alcohol it is possible to determine if the coloring matter present is natural (flavescen) or due to an added, artificial coloring material such as caramel or synthetic dye.<sup>19</sup>

*Alkaloids* — These substances are detected by precipitation, using an alkaloidal reagent such as mercuric potassium iodide on the original sample (see Chap. 33).

*Heavy Metals* — Inorganic compounds are detected by precipitation with hydrogen sulfide, first in acid medium and then in alkaline medium.

Esters, fusel oil, glycerol, sugars, fixed and volatile acids are other determinations that would be included in a complete examination, but for the purposes of police work, it is very seldom necessary that they be made.

### EXERCISES

1. The student should familiarize himself with the exercises given in Chap. 7 and Chap. 40.

2. Obtain three bottles of beer, each of a different brand. Without distilling, determine the percentage of alcohol in each sample by both the refractive index and specific gravity methods.

3. Distil the samples used in exercise 2, and determine the percentage of alcohol in the distillates by both specific gravity and refractive index methods. Compare the results with those obtained in exercise 2. Which set of measurements gives higher apparent percentage alcohol? Account for this. Save the distillates for exercise 5 below.

4. Repeat exercises 2 and 3 using whiskey; wine; brandy; gin; hard cider.

5. Add a known amount (in the region of 30 per cent) of methyl alcohol to four of the distillates that were obtained in exercises 3 and 4 above. Determine the percentages of ethyl and methyl alcohol in these prepared mixtures. Compare your results with the known composition.

6. Following the directions, perform the iodoform test on methyl alcohol, ethyl alcohol, propyl alcohol, isopropyl alcohol, n-butyl alcohol, sec-butyl alcohol, acetone. Note which compounds give positive reactions.

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# CHAPTER 28

## *DETECTIVE DYES, FLUORESCENT POWDERS AND RADIOACTIVE DETECTORS*

### **1. THE PROBLEM**

A common difficulty in detective work is the determination of the source of a substance or article, e.g., ink, gasoline, or money, for the purpose of connecting a suspect with a crime. This problem can be to a great extent solved, if there exists a means of chemically labeling the substance at its source or the article at its point of origin. In cases of recurring thefts or systematic sabotage the criminal can in this way be anticipated. The object of the crime, the tools which are to be used, or the area through which the culprit must pass can be treated chemically so that a suspect may be examined by merely looking for traces of the labeling chemical which was used. For example, the authors of "poison pen" letters can be identified by a chemical placed in the ink; the area surrounding the place where kidnap ransom money is to be delivered can be characterized by sprinkling it with an appropriate chemical. The handle of a fire-alarm box from which false alarms are being sent repeatedly can be treated, and the hands of the crowd that collects can be scrutinized surreptitiously by the detective for the tell-tale stains.

### **2. GENERAL PRINCIPLES AND THE NATURE OF THE CHEMICALS USED**

In general, the technique of this investigative procedure is uniform: A chemical which is easily identified is placed in intimate contact with an article or substance which is likely to be touched by the culprit in the commission of the crime. The chemical selected is of such a nature that it is known never to be associated with the labeled material, unless added for this express purpose. Then, if the labeled material is later found on or in the possession of a suspect, vivid proof has been established with respect to his connection with the crime.

The chemicals usually employed are dyestuffs which stain the hands, or



fluorescent substances which are detectable in ultraviolet light; in addition, radioactive materials may also be used. These substances are used as powders or in solution. They may be of natural or synthetic origin.

If powders are used the factors to be considered in their selection are: color, i.e., the ability to blend with the object to be labeled, adhesive quality, and the difficulty required to remove the stain produced.

If a solution is used the main consideration is that of solubility. This, of course, depends upon the solvent and the nature of the labeling chemical, as well as *pH*, temperature, etc. If a liquid is to be labeled the solvent selected to dissolve the labeling compound must be miscible with it. In addition, there must be no interference with the normal use of the liquid. Thus a substance which might corrode metals cannot be used to label gasoline because of its possible effect upon the gasoline tank or engine.

### **3. DETECTION OF PETTY THIEVERY BY THE USE OF DYES AND FLUORESCENT POWDERS**

Recurring thefts from lockers, dormitories, large offices, or other places of ready access to many people present a tedious problem to the detective if he attempts to solve the case by lying in wait to observe the thief in action. A simpler solution of such a case can be reached by powdering the probable area or objective of the theft with a substance which can be easily observed later on the hands or clothing of the guilty person.<sup>1</sup>

#### **Technique**

The powder is carefully dusted on a pocketbook, wallet, pocket lining, drawer, door knob or other object which the thief is likely to touch. On outdoor surfaces such as fire-alarm box handles, railroad car doors, garage locks, etc., an oil solution of the dye may be used. When the thief touches the treated object, some of the dye clings to his hand. Soon after this contact a stain develops; it is not readily removed except by the most careful washing. Naturally, the success of the ruse is dependent upon some observer who shares the confidence of the authorities and who will call in the detectives as soon as he sees the stain upon the hands of any person.

A number of powders are listed in Table 16. A powder of the same color as the object should be chosen for the additional secrecy afforded by camouflage. For example, dollar bills or bonds would be powderd by a feather duster with crystal violet. Rhodamine B may be used for brown leather wallets. If the criminal is aware of the possibility of such a trap he will attempt to wash off the dye immediately. Many dyes may be washed off with soap and water without too great difficulty; hence the wash room should be within the observer's zone of surveillance. The thief may resort to the use of gloves or a handkerchief which can easily be discarded. For these cases, it would be well to use a fluorescent powder. Such a powder will become visible by fluorescence under an ultraviolet lamp. A portable ultraviolet lamp can be brought to the scene



crimes of sufficient gravity. As soon as the theft of the powdered wallet or other labeled article is discovered, all persons in the premises should be requested to subject their hands and clothes to an ultraviolet examination. Usually some of the powder will have clung to clothes of the guilty person, in addition to that which will be found on the wallet and perhaps on his hands (Fig. 200). Some dyes which stain are also fluorescent. Thus ultraviolet light frequently will reveal residual traces of the dye, usually found in the crevices bordering



(a)



(b)

**200. Fluorescent powder from a wallet is found on a trouser pocket and hand of a suspect: (a) as seen in visible light; (b) in ultraviolet light.**

the fingernails or in cuts and scars, even though all visible traces have apparently been removed by washing. It should be mentioned that lipstick and nail polishes contain dyes that fluoresce red, orange or yellow. Hence, in case of female suspects, fluorescence from this source should be expected in the facial area, on the hands, etc. Where an inorganic salt such as uranyl acetate is used, corroboration may be obtained by means of spectrographic analysis. Spectrophotometry also offers a method whereby it is possible to identify a dye uniquely. This is discussed in Chapter 43. Absorption maxima for various dyes are given in Table 16.

### Combination of Dyes

It is possible that the suspect may deny connection with the crime despite evidence of the dye. He may invent a reasonable explanation. When a difficulty of this nature is anticipated two or more dyes can be used to make the evidence more convincing. For example, rhodamine B can be applied in one



TABLE 16

NAME OF DYE OR POWDER	COLOR INDEX NUMBER	COLOR OF POWDER	COLOR IN WATER	U.V. FLUORES- CENT COLOR OF POWDER	U.V. FLUORES- CENT COLOR IN WATER	ADHESIVE QUALITY OF POWDER	DIFFICULTY IN WASHING OFF†	WAVE LENGTHS OF ABSORP- TION BANDS IN ÅNGSTRÖM UNITS
Rhodamine B	749	Brown	Cherry	—	Orange	Excellent	Considerable	5550, 5170
Eosine	768	Red	Red	—	Yellow	Excellent	Considerable	5163, 4835
Para Rosaniline- Sulfate	676	Purple	Plum	—	—	Excellent	Great	5439, 4871
Crystal Violet	681	Green	Violet	—	—	Excellent	Great	5910, 5405
Chrysoidine	21	Maroon	Orange	—	—	Excellent	Moderate	4831, 4524, 4285
R. S. Conc. Fluorescein	766	Maroon	Yellow	—	Brilliant Yellow	Excellent	Little but traces re- main for U.V.	
Naphtholate AS*		Mustard	Lemon	Yellow	Lemon	Excellent	Little but traces re- main for U.V.	
Malachite Green	657	Green	Bluish Green	—	—	Fair	Great	6169
Phosphine R Extra Conc.	793	Red	Orange	—	Red	Fair	Moderate	6678, 6093
Methylene Blue	922	Dark Green	Blue	—	—	Fair	Moderate	
Uranyl Nitrate		Yellow	Yellow	Yellow	Yellow	Less than fair	Very little but traces may remain for U.V.	

\* Information as to Color Index No. or Manufacturer not available on bottle used.

† Great &gt; Considerable &gt; Moderate.



on the hands of the suspect increases greatly the probability of his guilt (see Chap. 46).

Again, a fluorescent powder can be used in combination with a staining powder. In the event of the suspect's explaining away the stain, he would find some difficulty in the invention of a plausible reason for the presence of the fluorescent powder.

### Practical Aspects and Characteristics of Dyes

Table 16 gives useful data which will be of value in the selection and later identification of a dye. The dyes are listed in accordance with their usefulness as experienced by the authors.

When it is required that an object be labeled for a considerable period of time, and especially if it is to be exposed to varying weather conditions, a saturated solution of crystal violet, rhodamine B, or other dye in oleic acid ("red" oil) is more suitable than powder.

## 4. CHEMICAL DETECTORS FOR GASOLINE

The detection of systematic petty thefts of gasoline is both difficult and, over a long period of time, expensive if a detective is to be assigned on a "plant" until the perpetrator is caught. A simpler and more effective solution to use when such thefts have been noticed is to mark the fuel chemically.

### Technique

The chemical used to mark the gasoline is dissolved in a suitable solvent and added to the tank.\* This is done preferably just before the tank is to be filled so that the labeling material is well dispersed throughout the entire sample. A sample of the untreated as well as a sample of the treated gasoline should be obtained as controls.

A list of suspects should be drawn up. When the next theft is noticed, samples of fuel are taken secretly from the tank of each suspect's car. These samples are then examined for the substance which was used to mark the original gasoline.<sup>2</sup>

### Dyes and Indicators

There are many dyes which might be used to mark gasoline. In general, those dyes which change color upon the addition of acids and bases† have been found satisfactory. For example, phenolphthalein has been employed with success in a case reported by Kerr;<sup>3</sup> a quantity of about 14 mg of phenolphthalein per liter of gasoline was found to be sufficient. Other investigators<sup>4</sup> recommend that a slightly greater quantity (20 mg per liter) be used. Thus, to treat a 500-gal storage tank of gasoline,  $1\frac{1}{3}$  oz of phenolphthalein are dissolved in 15–20 fl oz of a suitable solvent such as ethyl or isopropyl alcohol.

\* This may be the large storage vessel of a gasoline station, the tank of an automobile or any other container from which it is suspected that gasoline is being stolen.

† Such dyes are called *indicators* by chemists.



The examination of gasoline suspected of having been pilfered is relatively simple. One ml of an aqueous solution of sodium hydroxide (5 per cent by weight) is shaken with about 10 ml of the gasoline; if a red color develops in the bottom (aqueous) layer, phenolphthalein is present, indicating that the gasoline examined was obtained from the treated supply.

While the familiarity of chemists with phenolphthalein undoubtedly accounts for its being employed first, there are other indicators which a further study of this problem would suggest because of their greater sensitivity.\* Thus bromphenol blue, bromcresol purple, and cresol red, to name a few, may be used instead of phenolphthalein.

### Fluorescent Materials

There are several aromatic coal-tar hydrocarbons such as chrysene  $C_{18}H_{12}$ , fluoranthene  $C_{16}H_{10}$ , fluorene  $C_{13}H_{10}$ , and anthracene  $C_{14}H_{10}$ , the remarkable fluorescent properties of which suggest that they would be a valuable means of marking gasoline. The authors have found fluorene and chrysene to be very satisfactory. For example, 2.5 mg of fluorene imparts a very distinct fluorescence to a liter of gasoline when viewed under ultraviolet light. Before using any fluorescent materials it is advisable to examine the untreated gasoline under ultraviolet light. If the gasoline already possesses fluorescent properties similar to those which it ordinarily would have after the fluorescent material is added, it would be wiser to use another method of labeling.

### Radioactive Substances

The use of radioactive materials as a means of labeling substances is discussed in section 6. The usual precautions of obtaining control samples will, of course, be observed even with this method of marking.

## 5. CHEMICAL DETECTORS FOR INK

Occasionally, it is necessary to demonstrate that the ink used in writing a document, record or letter was obtained from a particular source. For example, certain governmental or business records requiring authorization signatures or containing important information may be filed where they are accessible to minor employees who wish to introduce alterations for some purpose. Any later difficulties which might result from these alterations may be avoided, however, if it can be shown that changes were made in the document. It is possible to do this by merely marking the original ink used in writing the document.

Another instance in which marked ink would be of assistance is in the investigation of a suspect thought to be the anonymous author of annoying or threatening letters. In these instances the habits of the suspect should be studied and his source of ink located. This ink may then be marked as indicated below. If subsequent letters are written with the marked ink, the original suspicion is confirmed in startling fashion.

\* By greater sensitivity it is meant that a smaller quantity of indicator is required to mark a given volume of gasoline.



### Technique

An aqueous solution of the substance chosen as the labeling material is prepared. The concentration of the labeling solution varies with the substance used; recommendations as to the amount to be added are made accordingly at the appropriate places below.

### Fluorescent Materials

It is well known that naphthylamines are highly fluorescent in ultraviolet light. When they are to be used in aqueous solution, it is necessary to introduce a sulfonic acid group into the molecule in order to enhance its solubility. The authors have found that 1-naphthylamine-3, 6, 8-trisulfonic acid is very satisfactory for marking ink. A mixture of 5 volumes of ink (blue-black iron tannate type) to 2 volumes of a saturated solution (22 C) of 1-naphthylamine-3, 6, 8-trisulfonic acid results in writing with a characteristic greenish-yellow fluorescence. This is easily observed in filtered ultraviolet light after one has had an opportunity to become acquainted with the phenomenon to be observed. If instead of a 5:2 ratio, a 5:5 ratio is used (i.e., equal volumes), the yellowish-green fluorescence is obvious even to uncritical observers. This fluorescence does not last indefinitely; after the writing is several months old the intensity diminishes so that an experienced eye is necessary to detect its presence. Finally, after a few years the fluorescence seems to have vanished completely. It is possible to restore fluorescence to the writing by carefully rubbing a wad of cotton moistened with dilute sodium hydroxide over the ink line. If the document is important, great care must be exercised in the use of sodium hydroxide as it affects both the paper and ink. In this case an unimportant section of a line in the writing may be examined by using a bit of cotton wrapped around the end of a tooth pick.

It is reported by Plotnikov, *et al.*<sup>5</sup> that a mixture of 10 g of aesculin and 10 g of sodium salicylate in 100 ml of a 1 per cent sodium hydroxide solution is useful as a means of marking ink. According to these investigators 1 part of this solution added to 10 parts of ink imparts a satisfactory and durable fluorescence.

## 6. RADIOACTIVE SUBSTANCES AS DETECTORS

While chemists have been using artificially radioactive atoms\* in research as a means of tagging a molecule, their use has not been widespread because of the limited supply. Now, however, because of the accelerated developments in the field of nuclear physics and the advent of atomic energy, it is to be expected that artificially radioactive materials will be available in quantities that will permit of their use in many other problems. In the police field almost any situation which requires the labeling of a substance will accordingly benefit.

While it is not possible to specify the radioactive compounds that would be useful for each case in which such materials might be employed, it is nevertheless

\* A radioactive atom is one which has an unstable nucleus, spontaneously emitting corpuscular particles or electromagnetic radiations of very short wave lengths.



possible to state a general rule which will be helpful in many cases. "A radioactive isotope of one of the constituents of the substance being labeled should be employed wherever possible." Furthermore, it is advisable to employ, if possible, those isotopes which emit gamma rays. If only alpha or beta particles are emitted by the isotope selected it is necessary to recover the radioactive material from any liquid in which it may have been dispersed. The residue left after evaporation of the liquid is then examined for radioactivity. Thus to label ink, radioactive iron ( $^{59}_{26}\text{Fe}$ ) can be used; for gasoline however, radioactive iodine ( $^{131}_{53}\text{I}$ ) with a half-life period\* of 8 days can be employed.<sup>6, 7, 8</sup>

An excellent article by Tryhorn and Widdowson<sup>9</sup> suggests the use of naturally radioactive substances which remain after radon "seeds"† have decayed. They recommend applying solutions of the radioactive materials by means of a small camel's-hair brush to the object to be marked. Coins, fabrics and various types of paper documents were labeled by this means. In the case of the coins, it was possible to determine which of a group of coins was the one originally marked, even though some of the unmarked coins were slightly contaminated by having been in contact with the marked coin.

A Geiger-Müller tube counter (v.i.) is employed to detect the presence of the radioactive materials. It is extremely sensitive and is capable of unequivocally identifying radioactive traces of the order of  $10^{-4}$  g of radium at a distance of 1 meter. Even smaller quantities may be identified by bringing the counter closer to the object under examination. Because it is not possible to detect the presence of radioactive traces in any other way and since this apparatus is not readily available except to those working with radioactive materials, the method offers an exceptional means of secretly labeling articles for future identification. Furthermore, it is usually difficult to remove the radioactive material except by vigorous chemical treatment.

One limitation on the usefulness of artificially radioactive materials is that of obtaining isotopes of which the half-life periods are sufficiently long to serve the purpose of police investigations. On the other hand it is desirable, in most cases, from the standpoint of minimizing possible health hazards to have the half-life periods limited to a few weeks.

## 7. GEIGER COUNTERS<sup>10, 11, 12</sup>

Geiger counters are devices which permit detection of feeble alpha, beta, and gamma radiations, such as are found in natural and artificially radioactive substances. For purposes of illustration, it is easier to consider the simple point

\* In a radioactive substance the number of atoms undergoing radioactive transformation per second is proportional to the number present. Therefore, an exponential law obtains, and it is convenient mathematically to describe the time required for one-half the atoms present to undergo this spontaneous decomposition. Thus, *half-life* is a term used to indicate the time required for half of the atoms of a radioactive substance to undergo transformation with the emission of corpuscular particles and electromagnetic radiations from the nucleus.

† These are glass tubes which have been filled with radon and are used in the therapeutic treatment of cancer. Radon is an emanation product of radium; it is a rare gas which is radioactive itself, with a half-life period of four days.



counter originally suggested by Geiger. Figure 201 is a diagram of a Geiger counter.  $A$  is an aperture through which the radiations pass; it is made of thin glass, mica, or aluminum.  $T$  is a cylinder made of metal such as copper or brass.  $W$  is a fine tungsten or copper wire mounted coaxially with and insulated from the cylinder. A high potential difference  $V$  is maintained between the wire and the cylinder.  $R$  is a high resistance, while  $C$  represents the (distributed) capacity. The cylinder is filled with a gas under reduced pressure; the potential  $V$ , applied across the counter is just slightly less than that necessary to produce a discharge through the gas. When radioactive radiations pass through the cylinder,

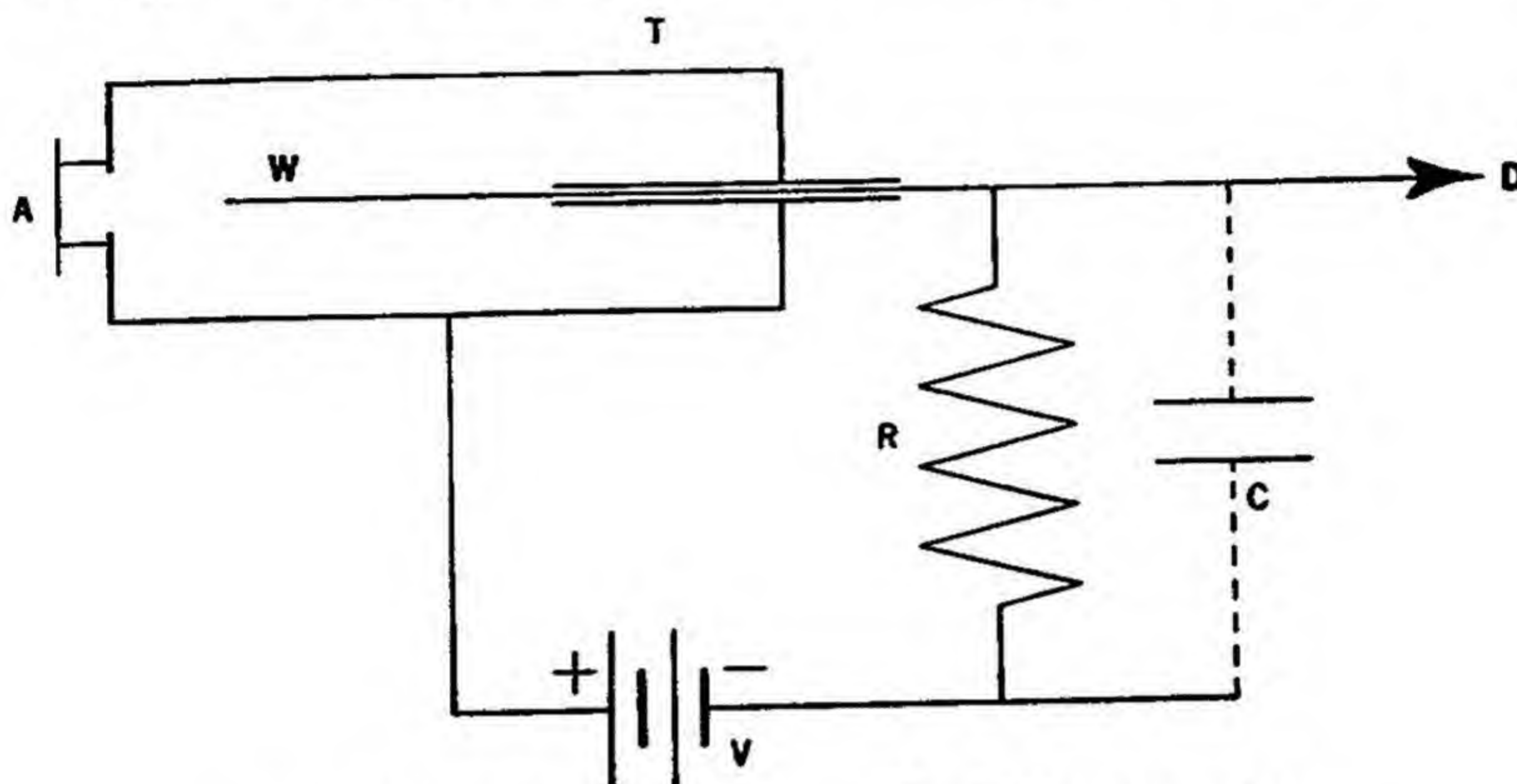


Fig. 201. Schematic diagram of a Geiger counter.

ionization of the gas occurs and a momentary current flows. This current may be detected by some device,  $D$ , such as an electrometer; if amplified, this current may be used to activate a loudspeaker or a mechanical counter.

The activation of the detector device attached to the Geiger counter is dependent upon the presence of radioactive substances and cosmic rays. Counts caused by the latter are termed *background*. Therefore to indicate the presence of radioactive substances there must be an increase in the number of counts over and above that arising from cosmic radiation. For a further discussion of the necessary statistical treatment of the data see Tryhorn<sup>13</sup> and Strong.<sup>14</sup>

In actual practice, Geiger-Müller counters are employed. Elaborate electronic circuits are used to increase the sensitivity of the counter. Tryhorn and Widdowson<sup>15</sup> have described a suitable amplifying circuit for a Geiger-Müller counter. In another excellent research, Curtiss<sup>16</sup> describes a portable Geiger-Müller tube counter which operates on relatively low voltages. Its sensitivity is such that one microgram ( $10^{-6}$  g) of radium can be detected at a distance of one meter. Since this instrument is convenient to use in the field because of its portability (it has a total weight of 13 lb) it is to be expected that ultimately this will become standard equipment in police laboratories. Portable counters are also available commercially.

## EXERCISES

1. Consult Table 16 and select a powder suitable to label a dollar bill; a brown wallet; postage stamps; a desk drawer; obtain these articles and actually label them with



the powders selected. Examine the articles after this treatment. Do they appear natural or is it possible to detect by visual inspection that they have been labeled? Place the articles so treated in their usual position and have a co-worker simulate a theft. Examine his hands immediately after handling the article; continue to keep his hands under observation until the tell-tale stains appear. Have him attempt to remove the stains by washing. Is this difficult? When the stain has apparently been removed examine his hands under ultraviolet light. In particular, notice the crevices around the fingernails.

2. Obtain several samples of gasoline from different sources; examine each under ultraviolet light and with a sodium hydroxide solution. Divide each sample into two portions of about 100 ml each. To each sample of one set add about 0.3 mg of fluorene; to each sample of the other set add 1 ml of ethyl alcohol containing about 2.0 mg of phenolphthalein per ml of alcohol. Examine the first set under ultraviolet light. Compare the treated sample with the original sample. Shake one ml of a 5 per cent sodium hydroxide solution with 10 ml of each sample of the second set of treated gasolines. What color develops? In which layer? Account for this.

Assume that gasoline is being stolen from an automobile. Label the gasoline in the tank of this car. Remember that a greater quantity of labeling material is needed in this case since it is quite possible that the pilfered gasoline will be diluted by its having been added to a partly filled tank of another car. A 10- to 20-fold increase in the quantities of labeling compound may be used to take care of this contingency.

3. Obtain several samples of ink, including inks of different color and of different manufacturers. Using a clean pen point in each case, write your signature with each ink before any chemical is added to it.

Pour a few ml of each ink into separate test tubes and add the recommended volume of the fluorescent solutions suggested in section 5. Shake the test tubes and allow them to stand for a minute before using. A series of writings, using a fresh pen point in each case, should be made again, placing corresponding inks in juxtaposition so that the fluorescent characteristics of the untreated ink may be compared with the treated ink. The different colored inks should also be compared with each other when viewed under ultraviolet light.

4. Prepare a saturated solution of crystal violet or rhodamine B in "red" oil (oleic acid). Brush a thin coating of this solution on a piece of iron pipe, a doorknob and a desk drawer handle.

Expose the iron pipe to the weather for one week. Examine the pipe to determine if handling it still causes the hands to be stained. Repeat this procedure, week after week, until handling the pipe no longer stains the hands. During this period keep a record of the weather.

Examine the doorknob and desk drawer handle daily until the hands are no longer stained by touching these objects. During this period keep a record of the frequency with which these objects are handled in the course of a day.

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# CHAPTER 29

## CHEMICAL TESTS OF POWDER RESIDUES

The examination of the residue that is left after the ammunition of a small firearm has been discharged is occasionally requested during the course of an investigation of a crime such as a suspicious death or an assault. The aspect of this examination with which the present chapter is concerned is that of the chemical tests employed in the detection of nitrates and nitrites in the residue. A common aim of these tests is that of obtaining data relative to the possibility of a death being suicide or homicide.

In the case of the nitrate test, a controversy exists over the value of making an examination of an alleged assailant's hands for nitrates, the presence of which is claimed by some to be indicative of his having recently discharged a gun. The history of the paraffin or dermo-nitrate test has been summarized by Castellanos,<sup>1</sup> one of its strongest advocates. The names given to this test are derived from the fact that melted paraffin is used to gather the nitrate particles from the surface and intradermic layers of the skin. The heat of the melted paraffin causes the pores of the skin to dilate and exude any particles which may be lodged therein. Diphenylamine is the chemical reagent used to detect the presence of nitrates in the paraffin gauntlet, consequently the test is sometimes referred to as the diphenylamine test. The technique of preparing a paraffin gauntlet is described by Castellanos and Plasencia.<sup>2</sup> Other investigations,<sup>3, 4, 5, 6</sup> including unpublished data obtained in the authors' laboratory, indicate that many exceptions may be taken to the favorable reports of these investigators. Thus in order to resolve these points of view and to evaluate any results that may be obtained from the paraffin-diphenylamine test, it is necessary to understand the nature of the chemical reaction involved.

In the case of the nitrite test, a procedure for determining the spatial distribution of the nitrites present in the powder residue present on a fabric was developed by Walker.<sup>7</sup> This procedure may be used as a means of estimating the distance (if not too great) from the muzzle of a gun to the initial contact point at the time of its discharge. As in the nitrate test, it is necessary to understand the nature of the reaction that is employed in order to appreciate its value. Before the chemistry of these reactions may be elucidated however, it is essential that the general composition of various types of powder be understood.

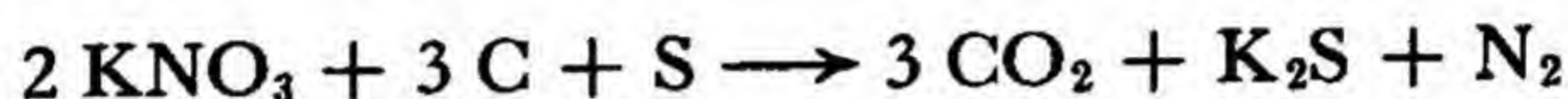


## 1. POWDERS

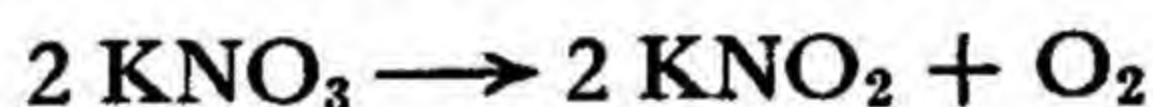
There are three types of powder used in the ammunition of small firearms — smokeless, black, and semismokeless. The most common is smokeless powder; black powder, although historically it preceded smokeless powder, has been replaced almost completely by the latter. Black and smokeless powders are sometimes used in combination as a semismokeless powder; this type of powder is employed even less frequently than black powder.

### Black Gunpowder

Chemically, black powder or gunpowder is an intimate mixture of potassium nitrate (saltpeter), carbon (charcoal), and sulfur, in the approximate ratio of 75:15:10. When this powder is fired in open space, the following chemical reaction takes place:



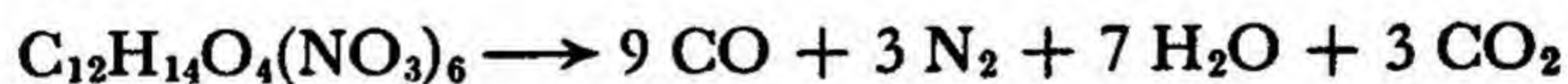
This reaction, however, represents an ideal situation. When the explosion occurs in a gun a much more complex reaction takes place. Substances such as potassium carbonate,  $\text{K}_2\text{CO}_3$ , hydrogen sulfide,  $\text{H}_2\text{S}$  (hydrogen comes from water present, as moisture), potassium thiocyanate  $\text{KCNS}$ , potassium nitrite  $\text{KNO}_2$ , and other compounds are found in the residue following an explosion of gunpowder in a firearm. The potassium nitrite probably forms as follows:



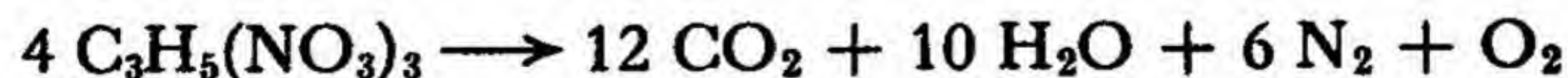
### Smokeless Powder

Smokeless powder consists of cellulose nitrate or glycerol nitrate combined with the cellulose nitrate. These compounds are commonly (but incorrectly) called respectively nitrocellulose and nitroglycerine. The chemistry involved in the firing of these compounds in the open follows:

*Cellulose nitrate:*



*Glycerol nitrate:*



Again, these represent ideal decompositions; they differ from that which actually occurs when the explosion takes place in a closed space such as in a firearm. Indeed, in order to reduce certain undesirable side reactions, which will occur if not hindered, certain organic and inorganic compounds are added to act as stabilizers, to aid in the proper firing rate of the powder and to minimize corrosive effects upon the metal of the gun. Among the inorganic compounds employed are nitrates, bichromates, and oxalates. Some of the organic substances used are nitrobenzene, graphite, and vaseline.

It should be noted that again nitrates are present in smokeless powder as well as in black powder. Thus we should expect to find nitrites in the residue in the

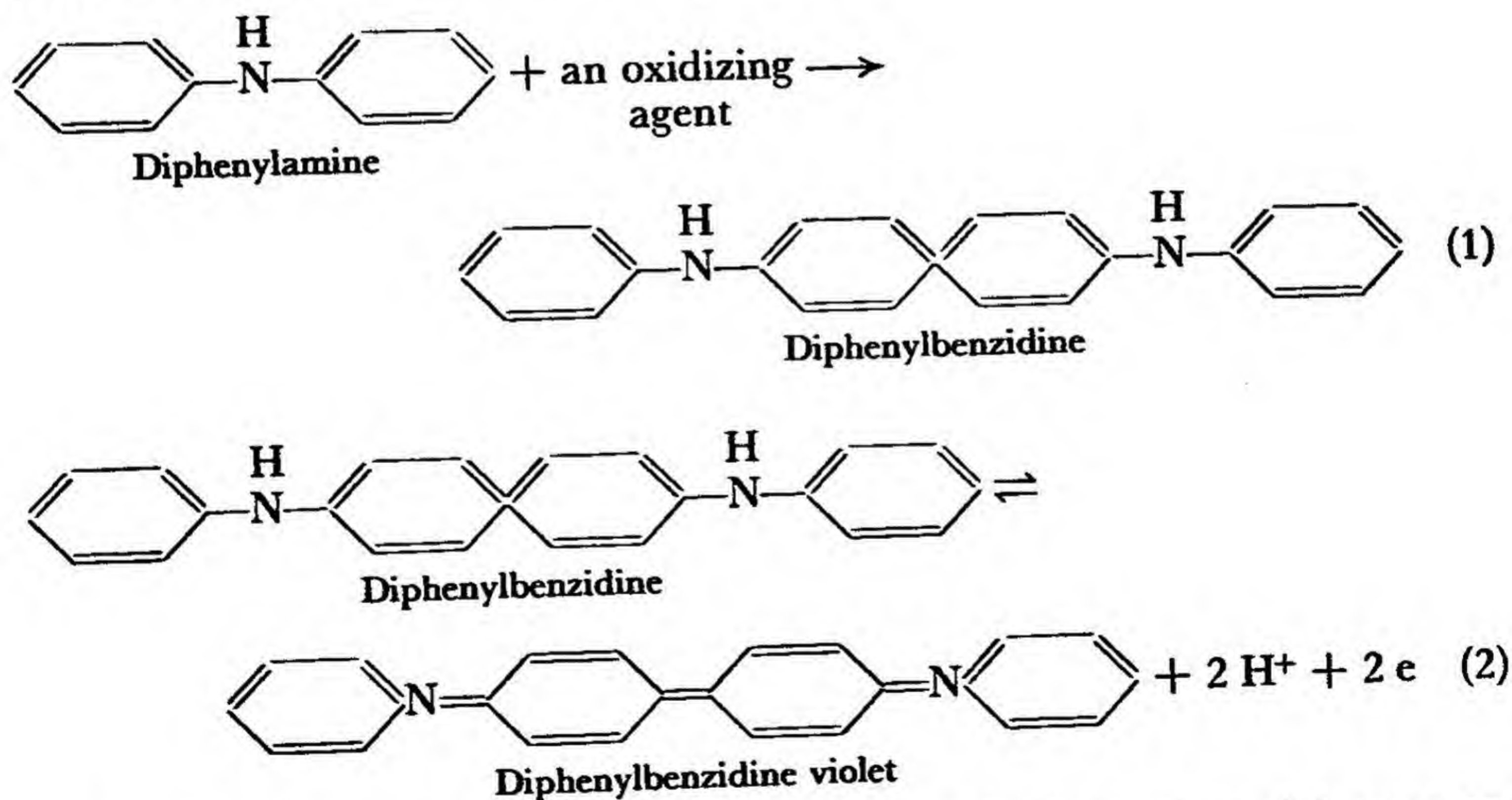


barrel of the gun, in or around the wound and on the clothing of the person fired upon if the range is sufficiently close.

## 2. THE PARAFFIN-DIPHENYLAMINE TEST FOR NITRATES

The procedure employed in carrying out this test is as follows: Clear, filtered, white paraffin (M.P. 38C–40C) is slowly heated until it has just melted. This liquid is then sprayed or poured over the fingers, hand, and wrists of the individual who is to be examined, until a coating of paraffin is obtained. This may be reinforced by thin layers of cotton or other fabric which in turn are covered with more melted paraffin until a cast  $\frac{1}{8}$  in. or more in thickness has been built up. This may be done first on the back of the hand and then on the palm. When the paraffin has cooled so that it has completely solidified, the cast is peeled gently from the hand.

The paraffin mold is examined by slowly adding the diphenylamine reagent with a pipette. This reagent is prepared by adding (with constant stirring) 10 ml of concentrated sulfuric acid to 2 ml of distilled water. To this solution add 0.05 g of diphenylamine and stir until the solid is completely dissolved. A positive reaction is indicated by the appearance of dark blue specks on the inner surface of the cast. It may sometimes require as long as twenty minutes for these blue specks to appear. The reaction may be interpreted as a two-stage oxidation of diphenylamine first to diphenylbenzidine (equation 1) and this in turn to diphenylbenzidine violet (equation 2).



Since the role of the nitrate is simply that of an oxidizing agent, it is apparent that the test is not specific.<sup>8</sup> Some false positive reactions will result, then, if the person's hands are contaminated by certain substances (with oxidizing properties) that are met with in the ordinary course of life. Thus, nonincriminating nitrates are found in fertilizers (farmers), explosives (miners), tobacco (smokers), firecrackers, urine, certain foods and cosmetics; laundry workers may have sodium hypochlorite or other bleaching agent on their hands; chemists and



pharmacists may also have small grains of oxidizing compounds on their hands. It is probably true, as many proponents of this test claim, that in general persons do not have nitrates or other oxidants on their hands as a matter of common occurrence. On the other hand, it is possible to discharge as many as 40 to 50 rounds of ammunition without obtaining a positive test for nitrates on the hands of the individual who used the gun.

Thus we have a situation similar to that of the Florence test; a positive reaction may be obtained without having discharged a firearm, and negative reaction may be obtained even after having discharged a firearm. A knowledge of these anomalies explains the otherwise unusual result obtained in the authors' laboratory in which a patrolman discharged several rounds of ammunition from his service revolver held in his right hand. The paraffin-diphenylamine test of this hand was negative while that of the left hand was positive. Obviously the suggestion that the two hands be examined, using one as a control, is no more a reliable procedure than merely examining the gun hand alone.

It is interesting to note that the Supreme Court of Pennsylvania<sup>9</sup> admitted the findings of a positive reaction with the diphenylamine reagent to be used as corroborative evidence that a defendant had recently fired a revolver.

### 3. THE WALKER POWDER RESIDUE TEST FOR NITRITES<sup>10</sup>

This test is designed to detect the presence of nitrites on cloth or other objects in the line of fire. From the pattern of distribution of the nitrite particles, it may be possible to estimate approximately the distance (if not too great) to the muzzle of the gun at the time it was discharged. In many respects this test is quite similar to that employed by sanitary chemists and bacteriologists who use sulfanilic acid and  $\alpha$ -naphthylamine in testing for nitrites in drinking water and sewage.

#### Preparation of Test Paper

Unexposed glossy photographic paper is immersed in new hypo solution for fifteen minutes so that all the silver salts are dissolved. The paper is then washed in running water for one hour, after which it is immersed in a 5 to 10 per cent aqueous solution of *C-acid* for ten minutes or longer, after which it is dried. *C-acid* is the common name of 2-naphthylamine-4, 8-disulfonic acid. Fresh *C-acid* paper must be prepared for each series of tests. An alternative procedure recently adopted by Walker employs imbibition paper swabbed with a 5 to 10 per cent solution of *H-acid*.<sup>11</sup> The advantage of this modification lies in the saving of time by eliminating the necessity of desensitizing and washing the photographic paper. In either case, the reagent (*C-* or *H-acid*) is made available for the reaction by having it dispersed in a tacky gelatin medium. Chemically, *H-acid* is 1-amino-8-naphthol-3, 6-disulfonic acid.

#### Procedure

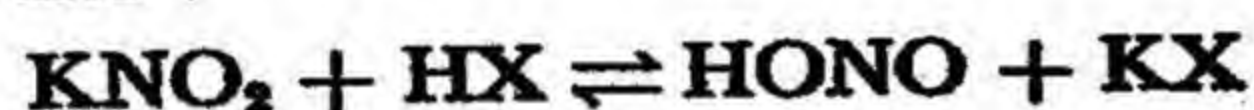
A clean bath towel is laid on a worktable; a piece of the prepared photographic or imbibition paper is laid face up on this. The fabric which is to be



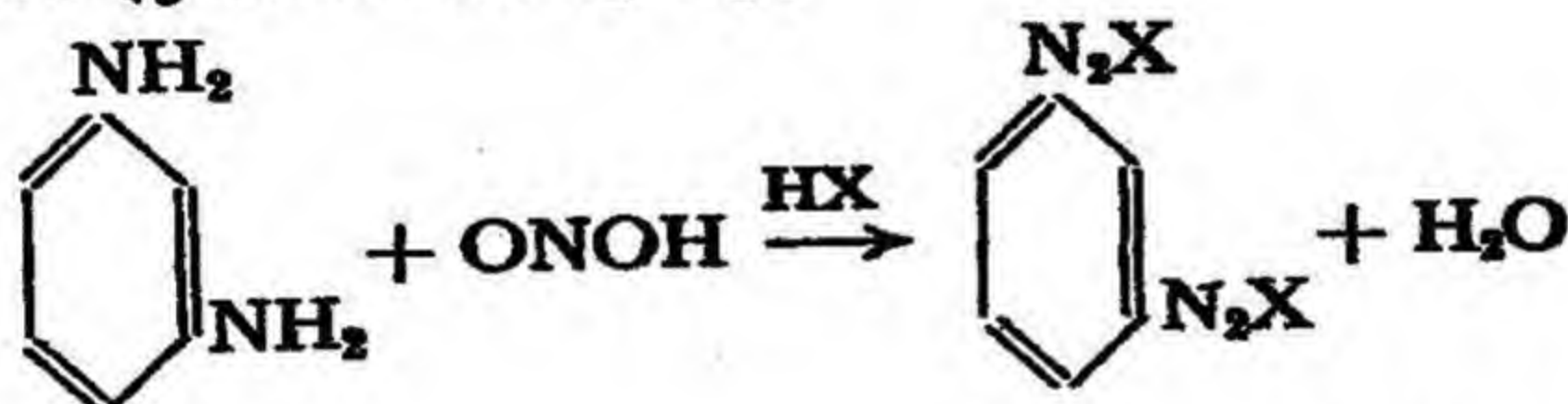
examined is then laid face down on the photographic paper. Over this, in order, are placed a thin dry towel or other cotton fabric, a towel moistened with 20 to 25 per cent acetic acid, and as a final layer another dry towel. This laminated arrangement is then pressed with a warm electric iron for five to ten minutes. When the photographic paper is removed, it will have imprinted upon it a number of red-orange spots which correspond exactly with the position of the nitrite particles in the residue about the bullet hole in the cloth. Of course the usual precaution of photographing (1:1 scale) any successful results should be observed since the dye may gradually fade or disappear from the paper.

In the test for nitrites, use is made of two well-known types of organic reactions known as *diazotization* and *coupling*.<sup>12</sup> An aromatic amine such as meta phenylenediamine (in the Walker test *G-acid* or *H-acid*) reacts in a dilute acid solution with potassium or sodium nitrite to form a diazonium salt. This in turn reacts with some of the remaining unchanged amine to form an azo dye, the color of which depends upon the amines involved, but generally varies from red or yellow to brown. Using meta phenylenediamine the following equations illustrate the principal chemical reactions:

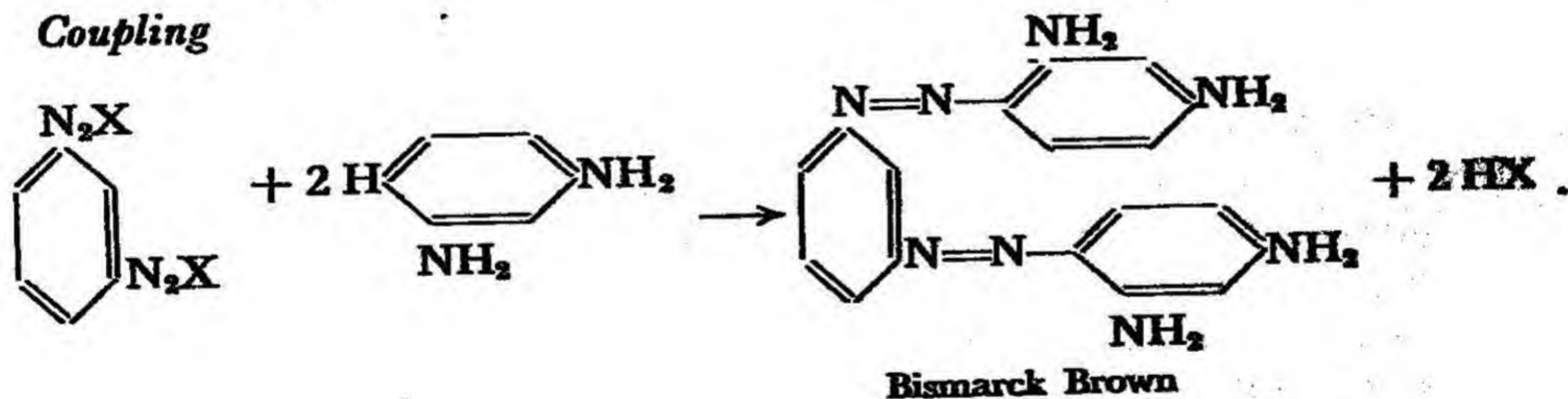
*Formation of nitrous acid*



*Diazotization (of each amine group)*



*Coupling*



It is known from organic chemistry that diazotization may be used as a specific test for nitrites; no other radical will give the reaction. Thus it is not possible to obtain a false positive test since oxidants in general cannot give the reaction, and nitrites are rather uncommon in occurrence, particularly on clothing or other material likely to be the subject of a powder residue examination.

This test may be useful in ascertaining if a hole in fabric was made by a bullet discharged from a short distance away. It may also be useful, when considered with other data, in estimating the approximate range at which the gun was discharged. In this connection it may offer some assistance in deciding



whether a person could have committed suicide or was shot by another. Of course the obvious precautions of using the gun which was involved in the original shooting, and similar ammunition (same manufacturer, type of powder, same lot number if obtainable, age, etc.) against the same type of target must be observed if the estimates are to be reliable.<sup>13</sup>

Since the situation most likely to prevail in these attempts to estimate the distance at which a shot was discharged is one in which complete control of all the variables is not possible, it is necessary to amass a large amount of experimental data so that the statistical variations may be considered before the estimate is made. In practice, several shots should be fired at two-inch intervals until a rough idea of the approximate range is obtained; then many more shots must be fired at each of the possible distances suggested by the preliminary test shots until a case can be made out for a pattern obtained at distance  $X$  as being similar to the original pattern. Of course distance  $X$  should be specified as lying between certain limits and not as an absolute distance. In those cases where the statement is made that the gun was discharged beyond the range of possible suicide, the lower limit must not be less than the distance at which the person could have held the gun.

## EXERCISES

1. Add 1 ml of ethyl alcohol to each of three test tubes. To the first tube add 50 mg of meta-phenylenediamine; to the second tube add a similar amount of benzidine; to the third tube add a similar amount of naphthylamine; to a fourth tube add a similar amount of *C-acid* and 1 ml of water; to a fifth tube add a similar amount of *H-acid* and 1 ml of water. To each tube add about 0.5 ml of 5 per cent acetic acid and shake. Are any color changes observed? Should any be expected?

Now add one small grain of sodium or potassium nitrite to the test tube containing the m-phenylenediamine. What color results? Repeat this step with each of the other test tubes containing benzidine, naphthylamine, *C-acid*, and *H-acid* respectively.

*C-acid* and *H-acid* are dye intermediates. They contain amino groups and therefore function like other amines; the disulfonic acid groups serve mainly to make them water soluble. If your laboratory possessed no *C-acid*, or *H-acid*, could you still perform the test?

2. Obtain several pieces of clothing or other cloth and, with proper precautions, discharge (a) a smokeless, (b) a black-powder-charged cartridge (do not use blanks) from a .32 revolver, a .38 revolver and a .45 automatic, through the various pieces of fabric at distances from 1 inch, every two inches up to 24 inches, and then every foot up to 6 feet. Examine each of these pieces of cloth for their nitrite patterns. Preserve the results, labeling the back of the photographic paper with the pertinent data.

3. Using ammunition obtained from two different sources, have a member of the laboratory discharge a revolver at two different pieces of clothing material, noting the distance in each case. From a study of the nitrite pattern, determine the approximate range at which he discharged the shots. Perform any additional tests that may be necessary before making your decision.

4. Examine both hands of the man who discharged the gun in exercise 3, (a) immediately afterward, (b) the next day, by means of the paraffin-diphenylamine test.



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# CHAPTER 30

## *DETECTION OF CARBON MONOXIDE AND OTHER GASES*

### **1. CARBON MONOXIDE**

Carbon monoxide is a colorless, odorless, tasteless gas. It is slightly lighter than air and only slightly soluble in water. It forms an explosive mixture with air between the limits of 12.5 per cent to 74 per cent carbon monoxide. It is the product of the incomplete combustion of carbonaceous materials and rarely occurs in nature. It is classified as a chemical asphyxiant insofar as its effects upon man are concerned.<sup>1</sup>

In cases of death by carbon monoxide, the services of the laboratory are sometimes requested to determine the source of the gas. Not infrequently the request is made before an autopsy has been performed and the cause of death established definitely. The investigation should be made as soon as possible, since the source of the gas may be altered, thus rendering it impossible to achieve positive results. Usually the death has taken place in some enclosed area such as a room or garage. The source of the gas is generally some apparatus such as an automobile or a gas refrigerator in which the combustion of the fuel was incomplete.

The first step in the investigation should be an inquiry concerning the original state of the windows, doors, transoms, and the possible sources of the gas. These conditions should then be reproduced and the tests conducted. It is, of course, possible that owing to the excitement the person who discovered the body neglected to make notes on this matter; hence, failing positive results, a set of worse conditions (windows completely closed, etc.) should be assumed and the tests repeated. Since the premises have almost invariably been aired before the arrival of the police, it is impossible to determine the exact original concentration of carbon monoxide which existed at the time of the death.

### **Procedure**

The procedure followed is to test the atmosphere in the region about each gas appliance (gas range, gas refrigerator, hot water heater), coal furnace,

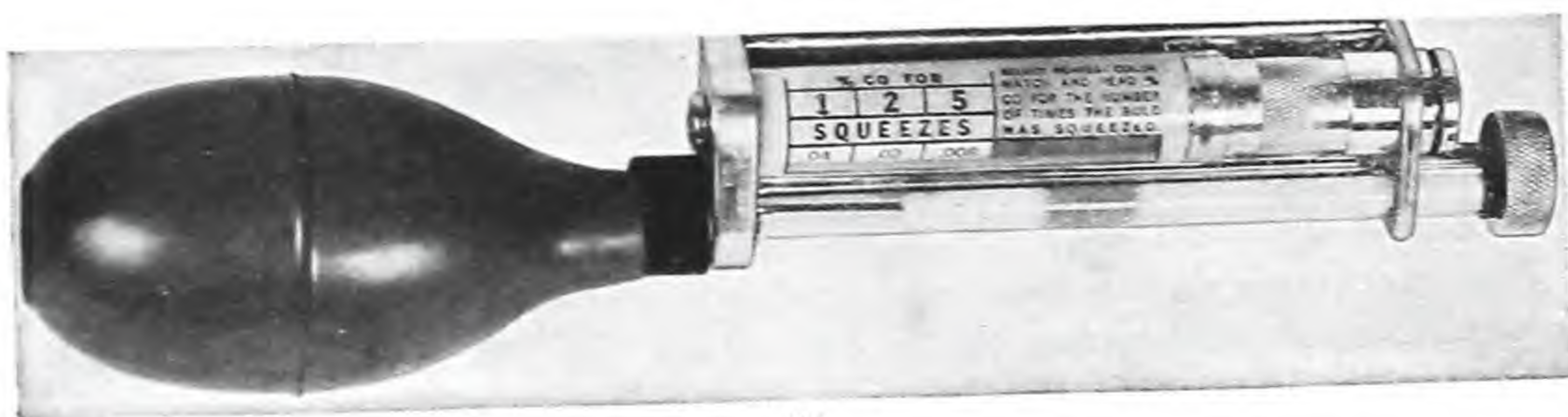


automobile, etc., with a portable apparatus which is manufactured commercially (see Fig. 202).

Those gas appliances having a stopcock which must be ignited at the orifice may require one-half hour or longer to build up a sufficient concentration of carbon monoxide if the defect is small. Where, however, the appliance is grossly defective a shorter time may suffice. While conducting the tests it is advisable, as a protective measure, to use the indicator machine frequently throughout the time spent in waiting for the suspected appliance to build up a concentration of carbon monoxide.



(a)



(b)

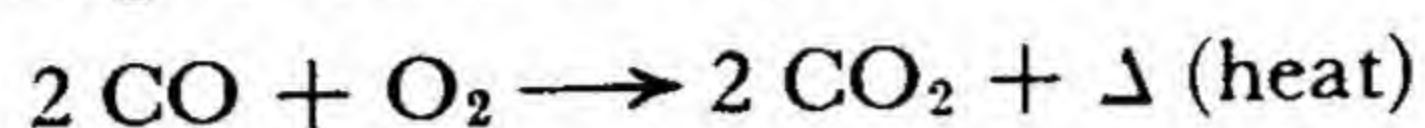
Fig. 202. Two types of portable carbon monoxide indicators.

Obviously the person in charge of the building in which any defective gas appliance is located should be informed of the danger and warned against permitting it to be used until the necessary repairs have been made. The laboratory should be called to conduct a check test on the adequacy of the repair job before the premises are again declared suitable for habitation.



### Principle of Instrument

The principle upon which the *Carbon Monoxide Indicator*\* (Fig. 202a) is based is relatively simple. A catalyst, called *Hopcalite*, is used to bring about the oxidation of the carbon monoxide to carbon dioxide. Since this is an exothermic reaction, heat is emitted in proportion to the quantity of carbon monoxide converted. The following reaction takes place:



The heat evolved is carefully measured by means of a set of differential thermocouples. These are connected to a millivoltmeter that is calibrated to read directly in terms of per cent by volume of carbon monoxide. The scale covers a range from 0 to 0.15 per cent and is graduated in hundredths of a per cent. It reads directly to 0.005 per cent ( $\frac{1}{2}$  part per 10,000 parts of air) and may be estimated to 0.001 per cent (1 part per 100,000).

### Toxicity

In most cases the detective conducting the investigation desires information concerning the toxic effects of carbon monoxide. The following treatment of this subject is given for that purpose.

The toxicity of carbon monoxide depends upon its greater affinity (about 300X) for hemoglobin than oxygen, and the greater stability of the carboxy-hemoglobin formed as compared to the oxygen analogue. In addition, the resulting retardation of the diffusion of the remaining oxygen of the oxyhemoglobin to the cell tissues by the carboxyhemoglobin causes a lack of oxygen where it is needed for maintaining the body processes, so that, effectively, the body is not poisoned but is rather suffocated or asphyxiated.<sup>2</sup>

The factors upon which the effects of carbon monoxide depend are:

- (a) the concentration of the gas
- (b) the length of time of exposure
- (c) the respiration rate — this depends upon whether the person is resting as in sleep, or reading, or exercising as in eating or doing housework. The higher the rate of respiration, the more dangerous the existing concentration, other conditions being equal.
- (d) the temperature and humidity (these affect the blood circulation; hence, as they increase they cause a more rapid combination of carbon monoxide and hemoglobin)
- (e) the individual — this is a subjective factor.<sup>3</sup>

Obviously it is difficult to state quantitatively a relationship which encompasses all these factors, but the following (within reasonable limits) may prove useful as a guide:<sup>4,5,6</sup>

$$P \sim C \times T$$

\* Manufactured by the Mines Safety Appliance Co., Pittsburgh, Pa.



where  $P$  is a numerical value expressing the physiological effect upon a resting subject;  $C$  is the concentration of carbon monoxide expressed in parts per 10,000 parts of air; and  $T$  is the time of exposure in hours.

	<i>Effect*</i>
When $P = 3$	No perceptible effect
$= 6$	A just appreciable effect
$= 9$	Headache and nausea
$= 15$	Dangerous

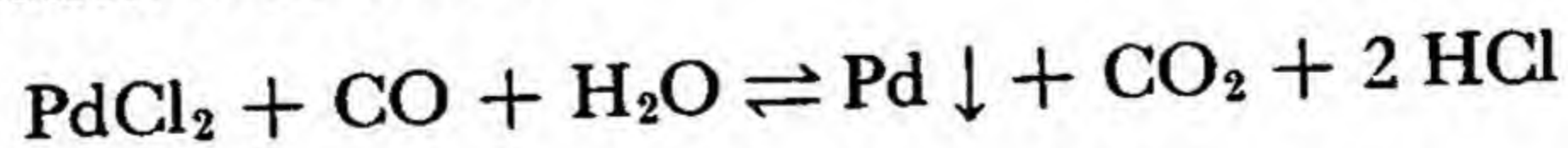
In case of physical exertion, the first value of  $P$  would be reduced from 3 to 2, 1, or even less and the other values would likewise be affected.

These data may be stated somewhat more elaborately as follows:<sup>7</sup>

<i>Parts of Carbon Monoxide per 10,000 Parts of Air</i>	<i>Effect*</i>
1	Allowable for an exposure of several hours.
4-5	Can be inhaled for one hour without appreciable effect.
6-7	Causes a just appreciable effect after one hour's exposure.
10-12	Causes unpleasant but not dangerous symptoms after one hour's exposure.
15-20	Dangerous for exposure of one hour.
40 and above	Fatal in exposures of less than one hour.

### Additional Tests for Carbon Monoxide

In the event that a *Carbon Monoxide Indicator* machine is not available, it is possible to detect carbon monoxide with an alternative chemical method. Strips of filter paper are saturated with a 1 per cent solution of palladous chloride ( $\text{PdCl}_2$ ) and allowed to dry. The test for carbon monoxide is conducted by wetting the palladous chloride strip with a 5 per cent solution of sodium acetate and exposing it to the suspected air for 10 to 20 minutes. In the presence of carbon monoxide the strip will darken, the intensity depending upon the concentration of the gas, length of time of exposure, and atmospheric temperature. The blackening of the strip results from deposition of finely divided palladium metal. The reaction is as follows:



An examination of this equation shows that the carbon monoxide functions as a reducing agent. We should not therefore expect this test to be specific for carbon monoxide. Thus it has been reported that gasoline vapor, ethylene, hydrogen, and hydrogen sulfide produce a color change similar to that produced by carbon monoxide.<sup>8</sup>

\* From *Noxious Gases*, 2nd ed., by Henderson and Haggard, copyrighted 1925 and 1943 by the Reinhold Publishing Corporation.



Mention should be made of the difficulty which is sometimes experienced in obtaining satisfactory results when this test is used. The reason for this may be that the compound, which is supplied as palladous chloride is, instead, basic palladous chloride or palladous ammonium chloride and as such is unsatisfactory since, among other things, it is not sufficiently soluble in water. In these cases the compound (ca. 250 mg) should be dried in an oven at 100 C for a period of an hour or more, after which it is placed in a beaker. The salt is then covered with 23 ml of water and 2 ml of concentrated hydrochloric acid and heated until it completely dissolves. Filter paper may then be impregnated with this solution. It is advisable to test all palladous chloride strips which are prepared in the laboratory by using a sample of gas which is known to contain carbon monoxide.

Quantitative methods for the estimation of the concentration of carbon monoxide in the atmosphere also use palladous chloride as an essential reagent.<sup>9, 10</sup> The disadvantage of both these methods, however, is that they are laboratory methods and are not useful for quick determinations in the field. They may be of some value as a means of obtaining quantitative estimates later, after the presence of carbon monoxide has been demonstrated by qualitative tests.

Berger and Schrenk<sup>11</sup> have carefully examined several other methods that have been suggested as a means for detecting carbon monoxide in the air and determining its concentration.

Shepard,<sup>12</sup> in a preliminary report concerned with the rapid determination of small amounts of carbon monoxide in air, describes a method for field use which is simple enough so that even untrained personnel are able to obtain accurate results. However, preparation of the required colorimetric indicator gel (a silicomolybdate complex and a catalyst, palladium sulfate) is time consuming, and is not a simple procedure. The Mines Safety Appliances Co. have made available a portable instrument which they call a *Carbon Monoxide Tester* (Fig. 202b). This tester employs the indicator gel mentioned to detect carbon monoxide in quantities ranging from 1 part in 100,000 parts air to 1 part in 1000 parts air. The color of the gel when carbon monoxide is detected changes from its original bright yellow to a green or a bluish green. By matching the color produced with a color scale which is provided with the apparatus, the concentration of carbon monoxide is readily determined. The indicator gel is contained in a tube which also contains a guard gel to remove water, gasoline vapor, and other interfering substances.

## 2. CARBON DIOXIDE

Carbon dioxide is another gas which is occasionally responsible for deaths that appear to be of a suspicious nature until the cause of death is ascertained. Rooms that are not properly ventilated while using heating and cooking appliances may have the oxygen depleted and carbon dioxide content built up to a dangerous level; ultimately the oxygen content may fall to a point where the air in the room will no longer support life. In these cases the laboratory will prob-



ably be of little value in helping to establish the cause of death, because of the practice of opening all windows in rooms in which death occurred. The results of the autopsy examination and the ventilation habits of the occupants of the room in which the death occurred must be studied for a complete diagnosis.

If the original conditions have not been altered too greatly — this may happen if the carbon dioxide was in a manhole, hold of a ship, pit near decaying organic matter, silo, deep well or cave — by the discovery of the body and the subsequent activities that followed, it is possible to collect samples of air which will be similar in composition to that which was present at the time of death. This may be accomplished by filling a gas collector with water, allowing the water to run out and to be replaced by the atmosphere. The sample can then be analyzed with little difficulty in the laboratory. Gas collectors may be metal tubes which taper at both ends and are fitted with rubber hose and clamps, or they may be made of glass with both ends equipped with ground glass stopcocks. The capacity of individual collectors may range from 50 to 100 ml or greater.

Carbon dioxide in small amounts (0.5 percent by volume) in the atmosphere stimulates respiration slightly but if breathed over long periods of time, minor physical discomfort as drowsiness or headache may result. When the concentration reaches 5 per cent by volume, breathing is laborious; 10 per cent can be endured for only a few minutes; at 12 to 15 per cent a person soon becomes unconscious; at 25 per cent death may take place. Again, the physiological effects depend upon concentration, time of exposure, physical exertion, temperature, humidity, health, individual predisposition, and air movement.<sup>13,14</sup>

### 3. OTHER DANGEROUS GASES

Occasionally sulfur dioxide, chlorine, hydrogen sulfide, ammonia, and other commercially used gases are the cause of untoward incidents, resulting in illness

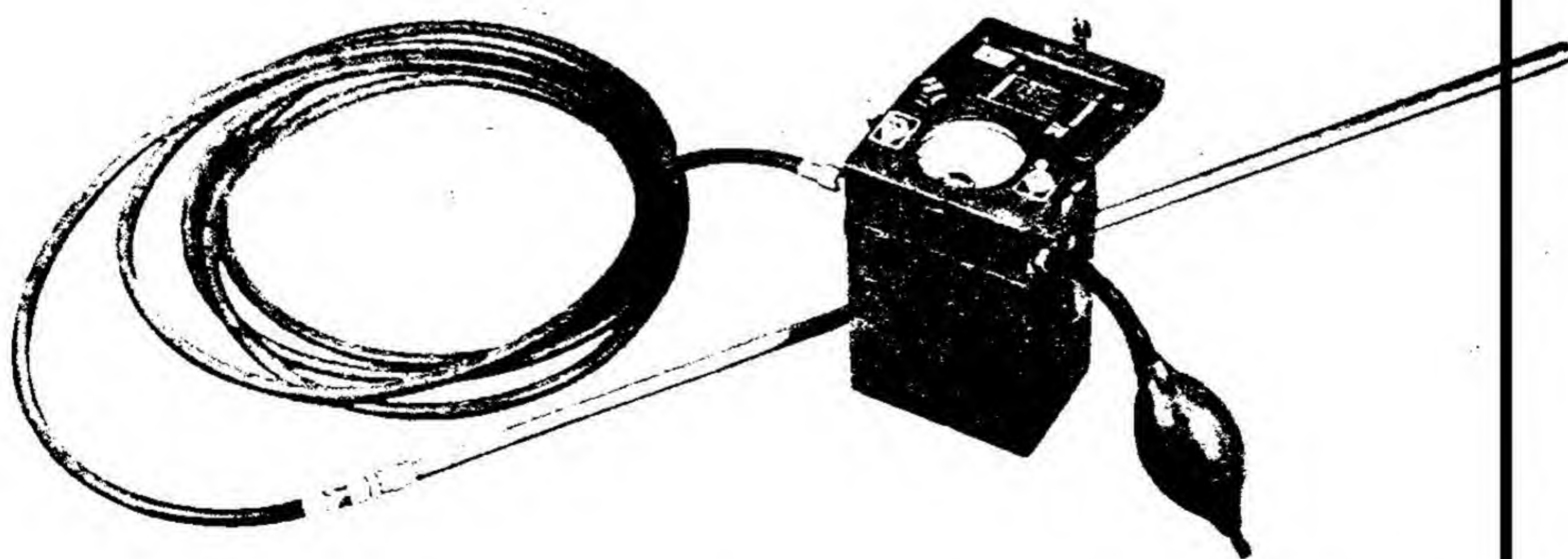


Fig. 203. Explosive gas indicator.

and occasionally death. The characteristic, sharp, pungent odors of most of these gases are sufficient to identify them, and their particular source is usually



obvious. Thus, sulfur dioxide and ammonia may be released when defects appear in mechanical refrigerator systems; while chlorine and other gases may escape from a defective cylinder.\*

The investigator in these cases would be required to collect test samples of the gas particularly if any laws or regulations governing the manufacture, storage, transportation, or use of these gases have been violated. The samples are taken as described above for carbon dioxide. Directions for laboratory analysis of these gases may be found in Jacobs<sup>15</sup> or Zhitkova.<sup>16</sup>

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15. *Ibid.*

\* A famous incident occurred in Brooklyn, New York, in June, 1944, when over six hundred persons were affected in varying degrees — some seriously enough to require hospitalization, others developing only mild symptoms — by chlorine gas which escaped from a small hole that developed in the bottom of a cylinder while in transit in a truck.



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# CHAPTER 31

## BLOOD

Frequently, traces of blood are left on the weapons or instruments used in the commission of crimes as well as on the clothing of both the injured person and the perpetrator. Blood evidence, therefore, may be extremely important in establishing the possibility of guilt or innocence of a person held in connection with a crime. The greatest evidentiary value results from an examination of a blood stain found on a suspect when the group of the stain and the blood group of the victim are the same, but different from that of the suspect. If the blood groups of victim and suspect are the same, the evidentiary value of the stain is considerably reduced, since the suspect can claim that it is his own blood. Tests on an alleged blood stain may, in certain cases, be used to exclude some suspects who are being held for investigation. If the stain is not blood, or is blood of a group different from that of the victim, the value of the results is negative in character and may be used to eliminate the suspect involved.

It is obvious, therefore, that a laboratory investigator must be familiar with the methods of testing blood. He must be able to determine if a stain might be blood; and, if so, whether it is human blood. Further, he should be able to group the stain where it is possible. The field and laboratory tests used in these examinations are described below.

### 1. THE COMPOSITION OF BLOOD

Blood consists of a fluid portion called *plasma* and various solid substances called *formed elements*. The latter include the red corpuscles (erythrocytes), white corpuscles (leucocytes), and platelets (or discs).

*Serum* is the clear light yellowish fluid which exudes from a cut or wound immediately after a clot has formed. In the laboratory, serum is employed in blood grouping tests. It may be prepared from whole blood by allowing the blood to clot, puncturing or removing the clot, and centrifuging the remaining fluid. The supernatant fluid after centrifugation is the serum. Serum differs from plasma in that it contains less protein, since fibrinogen (a plasma protein) is transformed into fibrin when the blood clot is formed. Serum also contains *brin ferment* a substance not found in plasma.



### Use of Saline Solution for Diluting Blood

It is found that red blood cells retain their shape and size, and the cell walls are not ruptured when added to a *saline* or *physiological salt solution*; whereas their addition to ordinary water causes the cell walls to be broken. When this happens the cells are said to be *hemolyzed* or *laked*. Physiological salt solution or normal saline solution is made by dissolving 1.7 grams of sodium chloride in 200 ml of distilled water. In an emergency in the field a satisfactory saline solution may be prepared by dissolving two heaping teaspoonfuls, of ordinary table salt in a quart of water. Saline solution exerts the same osmotic pressure on the cell walls from the outside as the cell constituents exert inside. The cell therefore remains intact and no disruption of the cell wall occurs. This is desirable, since it leaves the blood in a condition similar to that in which it is found in nature. Accordingly, when blood is to be diluted for test purposes, saline solution is employed.

## 2. PRELIMINARY OR NONSPECIFIC CHEMICAL TESTS FOR BLOOD

The first part of the examination that is made of an alleged blood stain consists of a preliminary chemical test to establish if the stain might be blood. Chemical tests are nonspecific and are employed, especially at the scene of the crime, as a means of rapidly screening various stains which are thought to contain blood. If the result is negative the stain cannot be blood; if positive, further examination is required. These tests are not conclusive because other substances such as certain chemical compounds, pus, and other body discharges, etc., occasionally give positive reactions also. Thus a positive chemical test is a necessary but not sufficient condition for a stain's being blood.

There are several chemical tests which detect blood diluted to parts per 100,000 or even to parts per 1,000,000. Accordingly, a small quantity of a very dilute sample is required for these tests. In those cases where the amount of blood is barely sufficient for the precipitin test the great sensitivity of the chemical tests is very desirable, since the available sample may be conserved for the former test. In general, however, the sensitivity of the chemical tests exceeds greatly the demands of the laboratory investigator, since the significant tests — the precipitin and grouping tests — require considerably more blood. The chemical test which is most widely used is the benzidine test, although other tests are also employed, especially the reduced phenolphthalein test.

### Benzidine Test

The reagent is prepared as follows: Place the amount of benzidine that will stay on the end of a spatula into a test tube. Add 20 ml of glacial acetic acid and 1 ml of 3 per cent hydrogen peroxide, and shake well. Excess benzidine should be present at the bottom of the tube, indicating a saturated solution.

In place of the free base (benzidine), benzidine dihydrochloride may be used. It will be found that it is more convenient to use benzidine dihydrochloride.



ride, particularly in the field, since the glacial acetic acid is unnecessary, distilled water being used to dissolve the compound instead.

When this reagent is added to a blood solution, a bluish-green color develops almost immediately. The benzidine reagent does not keep well and must be prepared just before it is to be used. It must be tested with known blood (usually carried for this purpose as a stain on filter paper) to ascertain that it has been prepared properly. This must be done before it is used to examine the unknown stain.

The procedure for making the test is as follows:

Scrape off a small fragment of the suspected stain if it is on a solid object, or cut a few fibers or a small area from the stained part of the cloth. Place the

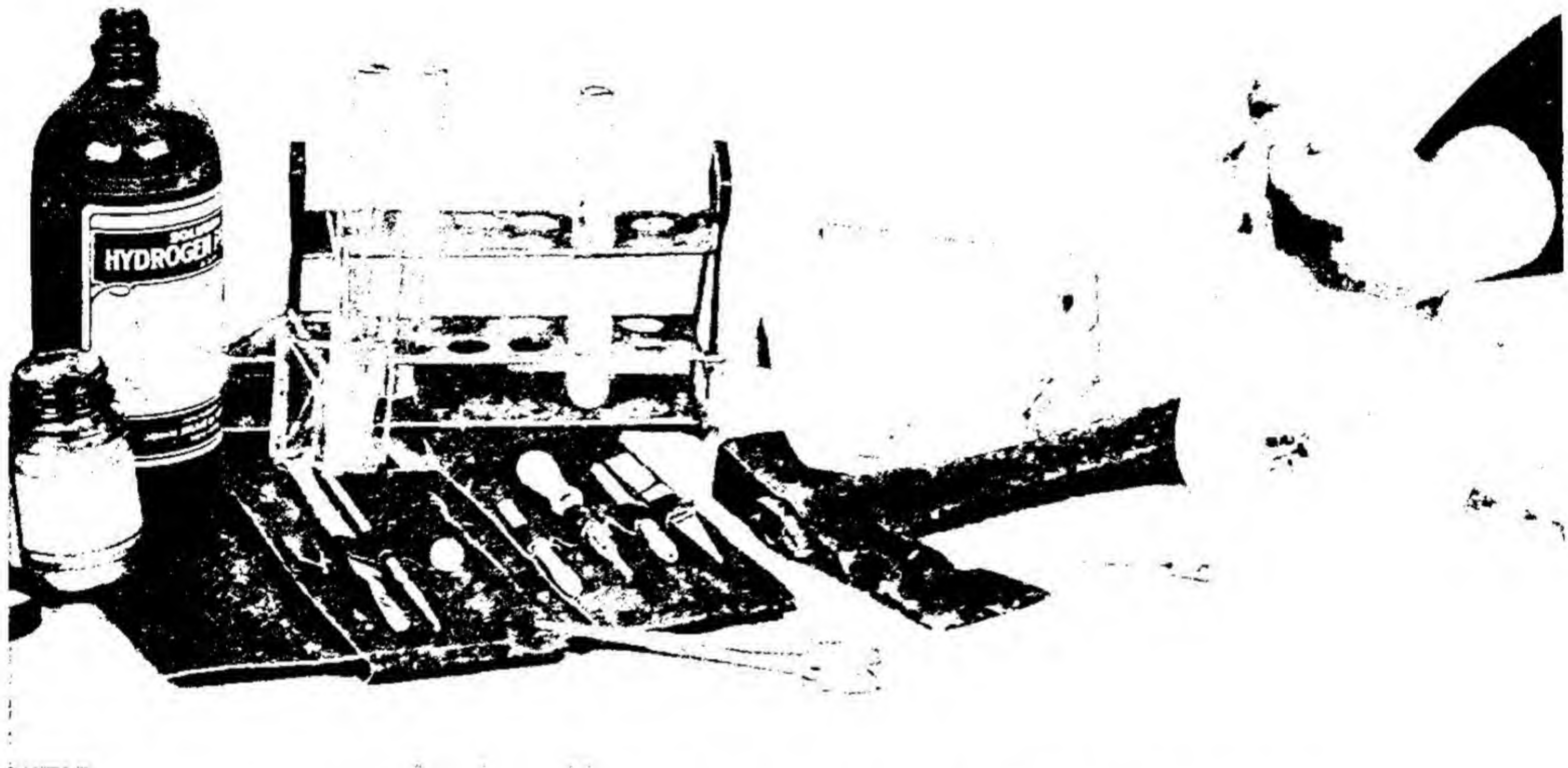


Fig. 204. Testing a stain on an axe with the benzidine reagent.

specimen on a piece of filter paper and moisten it with a drop or two of saline solution. After a minute or so, add a few drops of the reagent. The color should develop in a few seconds if blood is present (Fig. 204). If the stain is very old it may take somewhat longer for the color to develop. After a few minutes a blue color may develop even though no blood is present.

### Reduced Phenolphthalein Test

The reagent is prepared as follows: 1 to 2 grams of phenolphthalein are added to 100 ml of 25 or 30 per cent potassium or sodium hydroxide in a 250-ml round bottom flask. About 20 grams of zinc dust are added to the solution. A water-cooled condenser is attached in an upright position and the solution is refluxed until it becomes colorless. This solution may be kept by placing about 10 grams of granulated zinc in the container.

Five drops of the reduced phenolphthalein solution are added to 4 or 5 ml of a saline solution. An equal volume (4 or 5 ml) of 3 per cent hydrogen peroxide



is then added to the mixture. A few drops of this reagent are added to a saline solution of the alleged blood. If blood is present a rose color develops immediately. This test is perhaps the most delicate of all the chemical tests. The authors have detected fresh blood diluted 1 part to 5,000,000 parts of water with this reagent.

### 3. CONFIRMATORY LABORATORY TEST

It is possible to make further tests in the laboratory to establish that the positive result obtained in the preliminary examination was attributable to blood. One confirmatory examination consists of a chemical test for hemin. Nippe's modification of the Teichmann hemin crystal test may be used for this purpose. It is performed as follows:

Smear a drop of the extract of the unknown stain on a glass slide. Pass the slide through a column of hot air arising from a low Bunsen flame until it is dry. Add 2 drops of the reagent\* to the dried smear and place a cover glass over the preparation. Heat the slide very carefully over a low Bunsen flame until bubbles form under the cover glass, i.e., until the liquid just starts to boil. Now 1 or 2 drops of the reagent are allowed to seep underneath the cover glass; the slide is permitted to cool and is then examined under a microscope (100X). The crystals are rhombohedral in form and have a characteristic yellow to coffee-brown color.

This test is not easy to carry out successfully without considerable practice. When the sample to be examined is very limited in quantity it is better to eliminate this test and to use the available blood for the precipitin test.

### 4. THE PRECIPITIN TEST

After it has been established that blood is present in the substance under examination, the next step is to demonstrate that the blood is of human origin; otherwise a suspect can claim the blood to be that of an animal, picked up while hunting or in handling meat, etc. Therefore, it must be shown that a differential test between human and other bloods was performed, if the value of the evidence is not to be seriously impaired.

The test that is specific for human blood is the precipitin test. Actually, this is a test for the proteins that are contained in human blood. Antibodies that are specific for blood proteins of human origin may be prepared. These specific antibodies, which are called *precipitins*, react with human blood only, forming a precipitate when added to a solution containing human blood.

Precipitins are prepared by intravenously injecting an antigen (in this case, human blood serum) into a suitable animal, such as a rabbit. If appropriate precautions and proper technique have been employed, the blood serum of the immunized animal, which is obtained later by bleeding, will have developed antibodies or precipitins that are specific for blood of human origin.

\* The reagent is prepared as follows: Dissolve 1 g each of potassium chloride, potassium bromide, and potassium iodide in 100 ml of glacial acetic acid.



The blood serum obtained from the immunized animal is called *antihuman precipitin serum* or merely *human antiserum*.

### The Meaning of Titer

The ability of an antiserum to react with its antigen depends upon its strength. The term *titer* is used to indicate the units of antibody in the serum, i.e., to designate numerically the degree of strength of the antiserum. The titer value of an antiserum is estimated by titration experiments. Using exactly the same procedure, reagents, and other conditions of the test, progressively\* dilute (saline) solutions of the antigen are examined individually against the antiserum. The reciprocal of the most dilute solution of antigen which gives a positive test within a specified time limit† is the titer. Thus, antihuman precipitin serum which just gives a visible reaction at room temperature in 20 minutes with human blood serum diluted 1 part to 10,000 parts of saline solution is said to have a titer of 10,000.

A strong serum is generally preferable to a weak serum. Moreover, it is better to use serum of high titer that has been diluted than to use an undiluted serum of which the original titer is just about equal to that required for the test.

### Sources of Antisera

Antihuman precipitin serum, i.e., antiserum, may be prepared in one's own laboratory, if the necessary animals and equipment are available. Directions for the production of antiserum are available elsewhere.<sup>1, 2</sup>

For most police laboratories, however, it is more convenient to obtain antiserum from a commercial source.‡ Any antiserum which is obtained in this manner must be sterile and perfectly clear from cloudiness or sedimentation if it is to be regarded as suitable for forensic work. In addition, each batch of antiserum must be tested to determine if its titer strength and specificity are satisfactory.

### Equipment

The precipitin test is conveniently performed and requires a minimum of sample if *microtubes* are used. These tubes are prepared from approximately 8-cm lengths of ordinary glass laboratory tubing, the inside diameter of which is about 3 mm. One end of the tubing is inserted into a Bunsen flame until it has been sealed. Capillary pipettes are employed to add the various solutions required for these tests to the microtubes. A pipette may be made by drawing out ordinary 7- to 8-mm glass tubing to a fine capillary about 1 ml in diameter. A new pipette should be used for each solution added to a tube. This precaution

\* For example in the precipitin test, 1:500, 1:1000, etc.; in grouping tests 1:2, 1:4, 1:8, etc. or 1:3, 1:9, etc.

† In the precipitin test, 20 minutes; in blood-grouping tests, 5 minutes.

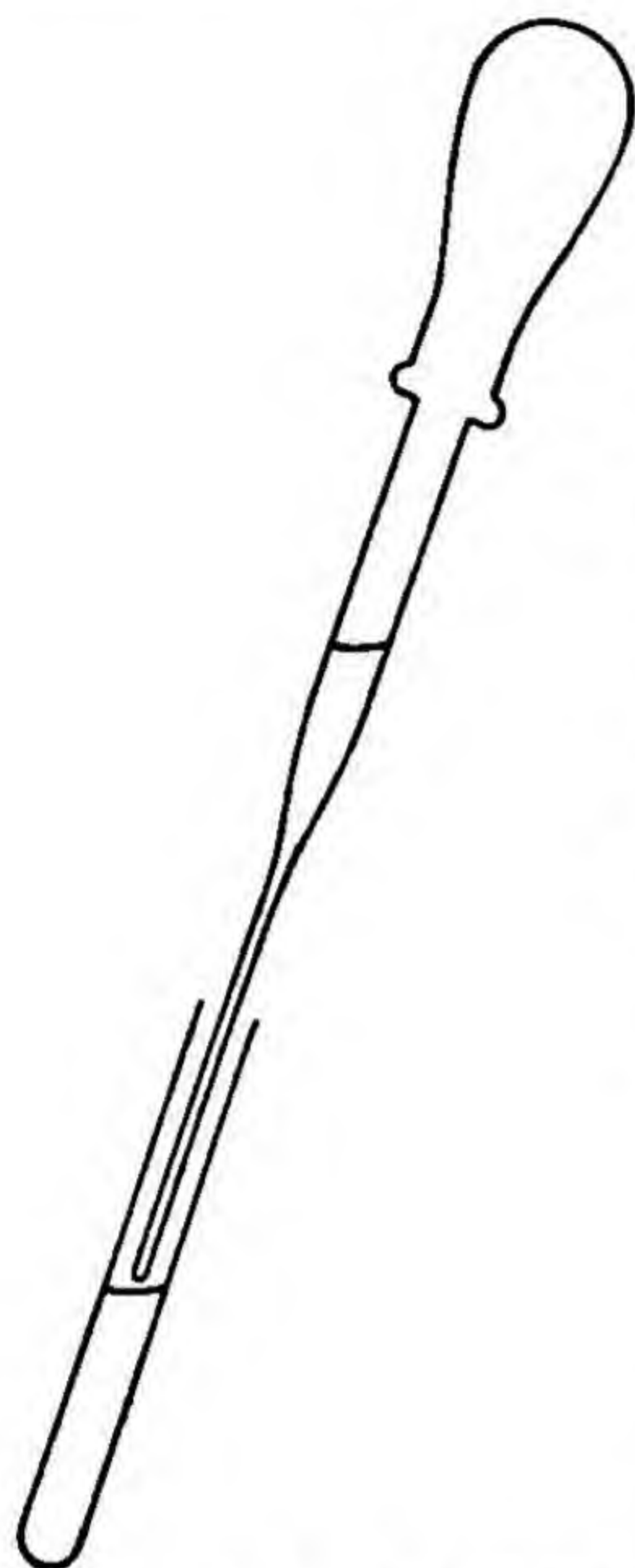
‡ For example, Alexander S. Wiener Laboratories, 64 Rutland Rd., Bklyn., N. Y., or Parke Davis & Co., Detroit, Mich.



is advisable as a measure of insurance against the contamination of one specimen with another.

### Determination of the Titer of Antiserum

In each of a series of seven microtubes place about 0.05 ml of human antiserum. In the first tube carefully pipette 0.05 to 0.1 ml of human blood serum diluted 1:500.\* Special care must be taken to obtain a sharp line of demarcation between the two layers. This may be accomplished satisfactorily if the tube is held in a sloping position and the tip of the capillary is slowly withdrawn as the serum flows out under the slight pressure produced by gently squeezing the rubber bulb (Fig. 205). A little practice in this manipulation is required in order to prevent air bubbles from forming throughout the liquid and particularly at the interface of the two liquids. In the second tube add 0.05 to 0.1 ml of human serum diluted 1:1000; in the remaining five tubes the following dilutions of human serum are added respectively: 1:2000, 1:4000, 1:8000, 1:16,000 and 1:32,000. A clean pipette must be used for each solution.



**Fig. 205. Stratifying precipitin serum.**

A positive reaction is indicated by the formation of a faint white cloud or ring at the junction of the two liquids. The demarcation is best observed by holding a small dark object (such as a ruler, card or fountain pen) in back of the tube directly in the path of the light and at the boundary line of the two liquids.

The reciprocal of the last dilution which, at room temperature, just gives a visible reaction in twenty minutes is taken as the titer of the antihuman precipitin serum under examination. With human blood serum diluted 1:1000, it is desirable that the antiserum give a visible reaction almost immediately or at most in two minutes; after five minutes or so a definite precipitate should have formed. Antiserum with a titer of 10,000 or greater is quite satisfactory (and preferable) for forensic purposes, although serum of lesser titer, i.e., as low as 1000, may be used with caution.

### Preparation of the Evidence Sample

The precipitin test requires that a solution of blood serum diluted 1:1000 (approximately) be prepared from the unknown (or evidence) sample.

\* A 1:500 dilution of human blood serum is prepared by hemolyzing whole blood with a minimum of distilled water and then adding an equal volume of 1.8 per cent salt solution so that an isotonic concentration of salt (0.9 per cent) again is present. One drop of this in 8 ml of saline solution (0.9 per cent) will give about a 1:500 dilution. The remaining dilutions are prepared by further additions of saline solution. For example, a 1:1000 dilution is prepared by adding 16 ml of saline solution to 1 drop of the original hemolyzed blood solution; 1:1500 by adding 24 ml of saline solution to 1 drop of the hemolyzed blood, etc.



If the blood is fresh and unclotted at the time of the test, a 1:1000 dilution may be prepared according to the directions given in the footnote on page 404. Usually however, the blood has dried and it becomes necessary to extract the stain with saline solution. Old stains require a longer time than newly dried stains for extraction; if one-half hour or more appears to be required, extraction should be completed in the refrigerator.

Extraction of a stained area approximately the size of a half dollar with 20 ml of saline solution (or an area about 1 sq cm in size with about 2 ml of saline) results in a solution diluted about 1:50 with respect to its serum. If the stain is on a hard object such as a stone or knife, a little of the blood can be scraped off and dissolved in saline solution. Each 2 mg of powder per ml of saline is equivalent approximately to a 1:50 dilution. One ml of blood serum at a dilution of 1:50 may be diluted 1:1000 by adding 20 ml of saline solution. The following simple criteria may be used to judge when the approximately correct volume of saline has been added:

### *COLOR TEST*

Blood diluted 1:1000 with respect to its serum is almost colorless, although extracts of dried stains may appear very pale yellow in color. With experience some reliance may be placed upon this means of estimating the dilution. In those cases where the suspect has attempted to remove the blood (say, by washing a hammer or knife) the amount remaining may have to be dissolved in only a few tenths of a milliliter of saline in order for the dilution to be satisfactory. In this case color is the only means of estimating the dilution.

### *PROTEIN TEST*

When a few drops of 25 per cent nitric acid are added to a few milliliters of blood serum diluted 1:1000, and the solution is heated to boiling, a faint cloudiness develops. If a heavy precipitate forms, the extract requires further dilution.

### *FOAM TEST*

Shaking a test tube containing blood serum diluted 1:1000 causes the formation of a foam that persists for a short time in the tube.

When the proper dilution has been achieved, the solution must be tested with litmus paper or other indicator. If it is not neutral, acidity should be adjusted with dilute sodium hydroxide solution (about 0.1 per cent) until the solution is neutral; alkalinity should be adjusted with a dilute solution of hydrochloric acid (about 0.1 per cent) until the solution is neutral.

Any lint particles or other debris or sedimentation must be removed at this point by filtration or centrifugation until the solution is quite clear. The questioned blood sample is now prepared for use in the precipitin test.

### **Controls**

The precipitin reaction is quite sensitive; the possibility of false positive reactions must constantly be borne in mind. Accordingly, several control tests



are carried out simultaneously in order to establish definitely that the antiserum employed is satisfactory, both in titer and specificity, and that no accidental contamination or nonspecific positive reactions caused by other substances are responsible for the precipitate formed in the tube containing the extract of the questioned stain and the antiserum. The complete precipitin test, therefore, includes the following controls as an integral part of the test. The tube numbers refer to those listed in Table 17.

An extract of the unstained material (tube 1) — This determines if the substrate (i.e., the material bearing the stain) contains substances other than the blood stain which react positively with the antiserum. A negative result must be obtained in this tube.

Saline solution (tube 2) — The solvent must be tested to demonstrate that it contains no substance which gives a reaction with the antiserum. A negative reaction must be obtained in this tube.

Animal blood diluted 1:1000 (tube 3) — Heterologous bloods are used to show that the antiserum will not react with any blood except that of human origin. No reaction must occur in this tube.

Known human blood serum diluted 1:1000 (tube 4) — This is included in the controls to show that the antiserum reacts with human blood and that its titer is satisfactory. The reaction in this tube may be used as a standard for comparison with other positive reactions.

Normal rabbit serum (tube 5) — This is used to show that the extract of the questioned material will not form a precipitate with blood serum which does not contain human precipitins. No reaction should occur in this tube.

The control tubes and the tube with the unknown sample are arranged as shown in Table 17.

**TABLE 17. Arrangement of Tubes in Precipitin Test**

TEST TUBE NUMBER	1	2	3	4	5	6
UPPER LAYER (Test Solution)	Extract of unstained material	Saline solution	Animal blood (serum) diluted 1:1000	Known human blood serum diluted 1:1000	Extract of unknown stain diluted 1:1000	Extract of unknown stain diluted 1:1000
LOWER LAYER (Reagent)	Antiserum	Antiserum	Antiserum	Antiserum	Normal Rabbit serum	Antihuman Serum
RESULTS WHICH DEMONSTRATE THE PRESENCE OR ABSENCE OF HUMAN BLOOD	No reaction	No reaction	No reaction	A white ring forms at inter- face al- most im- mediately or within a few minutes	No reaction	A white ring, cloud- ing or turbidity formed at interface within 20 minutes or less



### Procedure for Precipitin Test

About 0.05 ml of the various reagents listed in the lower layer of Table 17 are respectively placed with capillary pipettes in the bottom of the microtubes. The test solutions listed in the upper layer are carefully pipetted into the microtubes respectively as indicated in Table 17 (see Fig. 205). A sharp line of demarcation must be obtained between the upper and lower layers. A clean pipette must be used for the addition of the various test solutions in order to avoid any possibility of contamination.

At the junction of the two liquids, which are kept at room temperature, a white cloud or white ring will be seen at the interface of the two layers in those tubes containing the specific substance with which the antiserum reacts. If this white turbidity occurs in tube 6 within 20 minutes and in tube 4 almost immediately or at least within a few minutes and does not occur in any other in 20 minutes, it may be said that the blood examined was of human origin.

If the suspect has claimed that the blood stain is that of an animal, known blood from an animal of the alleged species is tested against the antihuman precipitin serum in tube 3. In addition an extract of the stain should also be tested against precipitin serum anti to the blood serum of the alleged species of animal. For example, if it is claimed that the blood is from a chicken, anti-chicken serum should also be used to determine if any chicken blood is present in the stain. It is possible that the stain might contain animal blood or human blood. In the former case the suspect's assertion is substantiated; whereas in the latter it is demolished. If both animal and human blood are found in the stain, the forensic value is similar to that in which only human blood was present.

## 5. BLOOD GROUPS

In 1900 Landsteiner discovered by mixing the red blood cells of one individual with the serum of another individual, that human beings belong to different blood groups. In certain such combinations of red blood cells and serum Landsteiner found that the cells clumped together or agglutinated. This phenomenon of red cell *agglutination*\* was explained on the basis that the red blood cells contain an antigen or *agglutinogen* and that the serum contains normal antibodies or *agglutinins*. Further investigation showed that there are two such antigens in the red blood cells and two corresponding antibodies in the serum. The two antigens were, for convenience, named A and B and the two corresponding antibodies were named anti-A (or alpha) and anti-B (or beta). Later developments showed that an individual might have one of these antigens in his blood cells, or he might have the other, or both, or neither. Thus, four combinations are possible. A person having antigen A in his red cells belongs to group A; a person having antigen B in his blood cells belongs to group B; a person having both antigens A and B in his red cells belongs to group AB; a person having neither A nor B in his red cells belongs to group O.

\* Since blood cells and serum of the same species are involved this is sometimes termed *is agglutination*.



Whatever antigen a person has in his cells, the corresponding antibody or agglutinin is lacking in his serum. Obviously this must be so, for if a person has antigen A in his cells and antibody alpha, i.e., anti-A, in his serum, his own cells would be agglutinated. Thus, a group A individual has antigen A in his cells and beta antibody (anti-B) in his serum; a group B individual has antigen B in his cells and alpha antibody (anti-A) in his serum; a group AB individual has antigens A and B in his cells and no antibodies in his serum; a group O individual has no antigens in his cells and both alpha and beta antibodies in his serum. Groups A and AB can be further subdivided into groups A<sub>1</sub>, A<sub>2</sub>, A<sub>1</sub>B and A<sub>2</sub>B. Bloods of the A<sub>2</sub> subgroup give distinctly weaker reactions than those of the A<sub>1</sub> subgroup. Other systems of nomenclature that have been used to designate blood groups are shown in Table 18.

**TABLE 18. Designation and Distribution of Blood Groups**

SYSTEM OF NOMENCLATURE	BLOOD GROUPS			
International	O	A	B	AB
Jansky *	I	II	III	IV
Moss *	IV	II	III	I
Approximate Distribution of Groups in Per Cent (European Stock)	40	40	10-15	5

\* The international system of nomenclature is preferable to these historical systems of designating blood groups.

In order to produce agglutination, it is necessary to combine an agglutino-gen (antigen) with its agglutinin (antibody); thus, red blood cells containing the A factor can be agglutinated by sera of either group B or group O since both contain alpha agglutinin. Similarly, red blood cells containing the B factor can be agglutinated by sera of either group A or group O, since both contain beta agglutinin; group O cells cannot be agglutinated because they contain no agglutino-gen; group AB cells can be agglutinated by any one of the other three groups since group AB requires either alpha or beta agglutinin to agglutinate it and each of the other groups contains at least one of these agglutinins in its serum.

Examination of Table 19 shows that with sera of groups A and B, it is possible to classify any blood into its proper group. If A serum (i.e., anti-B) gives a positive reaction the agglutinated blood is either group B or AB. To distinguish between these, B serum (i.e., anti-A) is employed since it does not react with B blood but if it is AB blood a positive reaction will take place. Similarly, with B serum (i.e., anti-A) it is possible to identify groups A and AB; these may be separated further, using A serum (anti-B). If the sera of groups A and B fail to agglutinate the blood, it is of group O.



TABLE 19. Characteristics of the Red Cells and Sera of the Various Blood Groups

	GROUP O	GROUP A	GROUP B	GROUP AB
Agglutinogens in red cells	—	A	B	A and B
Agglutinins in serum *	alpha and beta	beta	alpha	—
Serum agglutinates red cells of groups	A B AB	B AB	A AB	—
Red cells agglutinated by sera of groups	—	B O	A O	A B O

\* Note: Serum containing alpha agglutinin is known as anti-A serum; serum containing beta agglutinin is known as anti-B serum.

## 6. SOURCES OF ERROR

Before studying the methods of grouping blood, mention should be made of the possible occurrence of false positive results owing to nonspecific aggregation of red cells.<sup>3, 4</sup> Thus, positive reactions that simulate true isoagglutination may be the result of bacterial contamination (bacteriogenic agglutination) or rouleaux formation (pseudoagglutination), the latter resulting from acute bacterial infections or pregnancy, in which the red cells stack up like coins, this being referred to as *rouleaux*. In addition, other nonspecific clumping may occur when the tests are carried out at low temperatures; this phenomenon is referred to as *cold-agglutination* or, when the serum and red cells of the same individual are involved, the phenomenon is termed *autoagglutination*.

False negative results will be mentioned in the various procedures where an awareness of this phenomenon is necessary.<sup>5, 6</sup> Negative reactions of this type may be the result of a reduction in reactivity or the destruction of the agglutinins or agglutinogens originally present. In particular, care must be exercised to prevent mistaking A<sub>2</sub>B for B or an A<sub>2</sub> for O because of the weaker reactivity of the A<sub>2</sub> factor.

In general, specific isoagglutination or the reactions by which blood may be grouped will take place if the proper techniques, including controls, are employed and the precautions regarding concentration (or dilution), temperature, and sterile conditions are assiduously observed.

There are two conditions in which blood may be found at the scene of a crime or on the clothing or other evidence belonging to persons alleged to be involved in crime; namely, as a dried stain or as fresh blood, i.e., as a liquid or in a partially clotted condition. The techniques of grouping under these circumstances are different, fresh blood being relatively simple and a dried stain being difficult and fraught with many pitfalls, depending upon its age, the nature of the substance (shirt, shoe, glass, etc.) on which the stain is found, the conditions to which it has been exposed, the quantity present, etc.



## 7. GROUPING OF FRESH BLOOD

### Preparation of Reagents

A 2 to 5 per cent suspension in saline solution of the red cells of the blood to be grouped is required. This is prepared as follows: Place 5 ml of saline

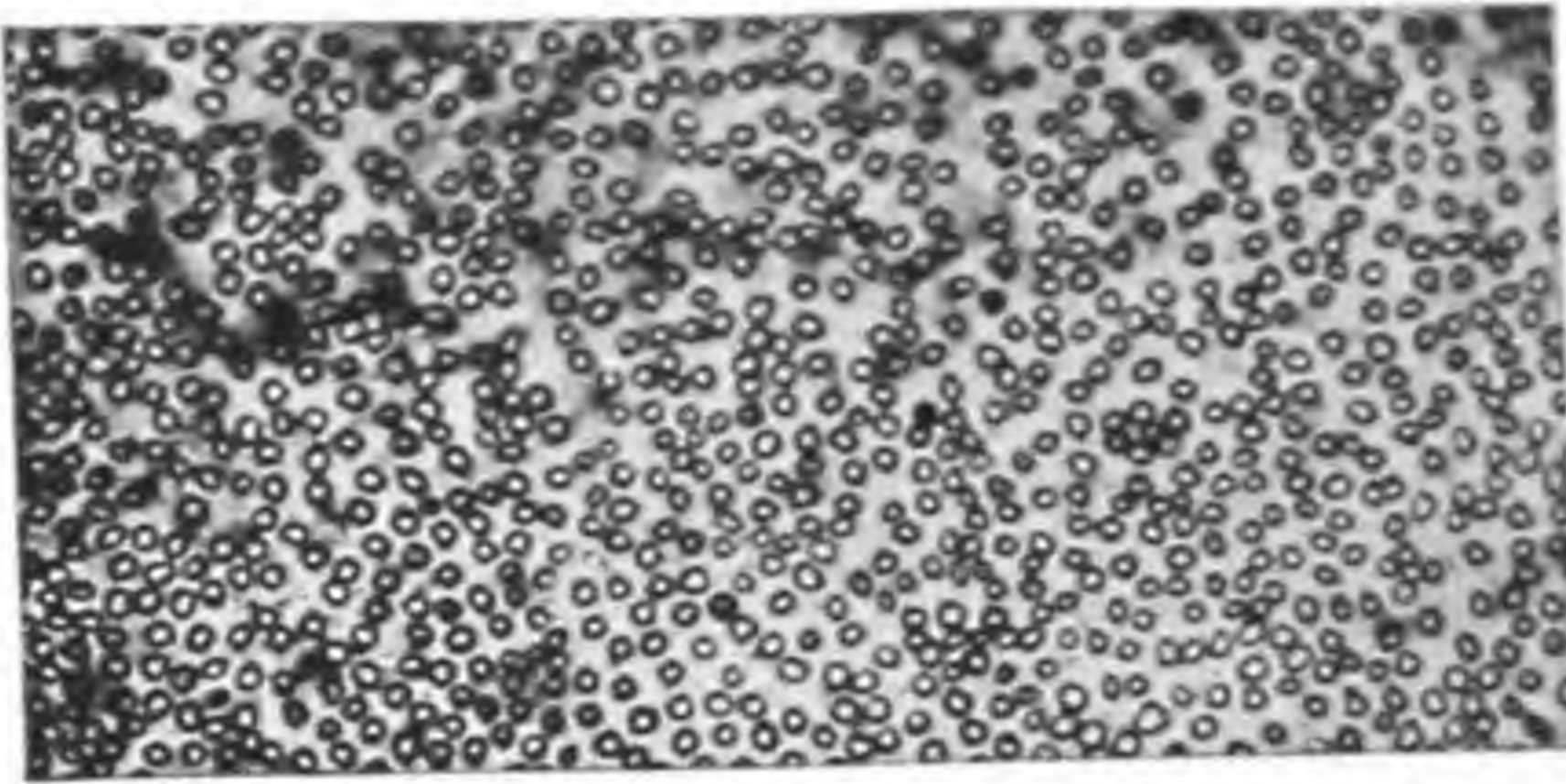


Fig. 206. Blood cell suspension suitable for grouping purposes (ca. 100X).

solution and 0.5 ml of a 3 per cent sodium citrate solution in a small test tube. If the test-tube method (v.i.) is to be used add 4 to 7 drops of the blood to be tested to the saline-citrate mixture; if the glass-slide method (v.i.) is to be used, 8 to 12 drops of the blood to be tested are added instead of 4 to 7. The solution has a light pink or cherry color when the cell concentration is in the desired

region. A microscopic examination may also be made to determine if the cell suspension is of the proper dilution (Fig. 206). With experience, however, visual inspection of the color will usually suffice.

Some serologists prefer to use cells that have been washed. This may be accomplished as follows: The tube containing the cell suspension is shaken gently for a few minutes. The contents of the tube are then centrifuged and the supernatant liquid is discarded. Five ml of saline solution are added to the sediment. The cells are resuspended by gently shaking the contents in the tube. The color should again be light pink or cherry.

Suspensions of fresh cells must be prepared on the day they are to be used; otherwise nonspecific reactions may result from the bacteria that have multiplied in blood prepared more than a day before it was to be used.

### Test Tube Method for Fresh Blood

#### *PROCEDURE FOR THE DETERMINATION OF AGGLUTINOGENS*

The small test tubes required for these tests may be purchased ready-made or they may be prepared from ordinary glass tubing with an internal diameter of 6 to 8 mm and cut into 7- to 9-cm lengths. The reagents are used (and the tests carried out) at room temperature.

Place one drop of a 2 per cent cell suspension of the blood to be tested in a small test tube. Add one drop of saline solution and then one drop of known anti-A serum. Repeat this procedure in another test tube except that in this tube the serum used is known anti-B. Shake the two tubes gently for about 10 seconds and set them aside. After a few minutes centrifuge the contents of both tubes for 2 to 3 minutes at 1500 to 2000 rpm. If no centrifuge is available, allow the tubes to stand for about 60 minutes.

After centrifuging (or standing 60 minutes) examine the tubes. The cells will be found to be packed (or settled) on the bottom of the tube as a sediment.



The results of the test are determined visually after shaking each tube gently once or twice. In this manner it can be seen with the naked eye or by microscopic inspection whether agglutination has taken place or not. If the sediment is not evenly dispersed but remains in a clump or clumps (Fig. 210, tubes 4 to 6) a positive agglutination reaction has taken place.

If the corpuscles (i.e., the sediment) are resuspended readily, dispersed evenly with no clumps and the original color is restored to the fluid then no agglutination reaction has occurred (Fig. 210, tube 2).

The agglutinogens present in the unknown blood are deduced from the results obtained in the tests. If known anti-A serum (alpha agglutinin) caused agglutination, the unknown blood contained cells with the A factor; if known anti-B serum (beta agglutinin) caused agglutination, the unknown blood contained cells with the B factor. If neither known serum caused agglutination, the cells were of group O; if both sera caused agglutination, the cells were of group AB (Table 19).

### Slide Method for Fresh Blood

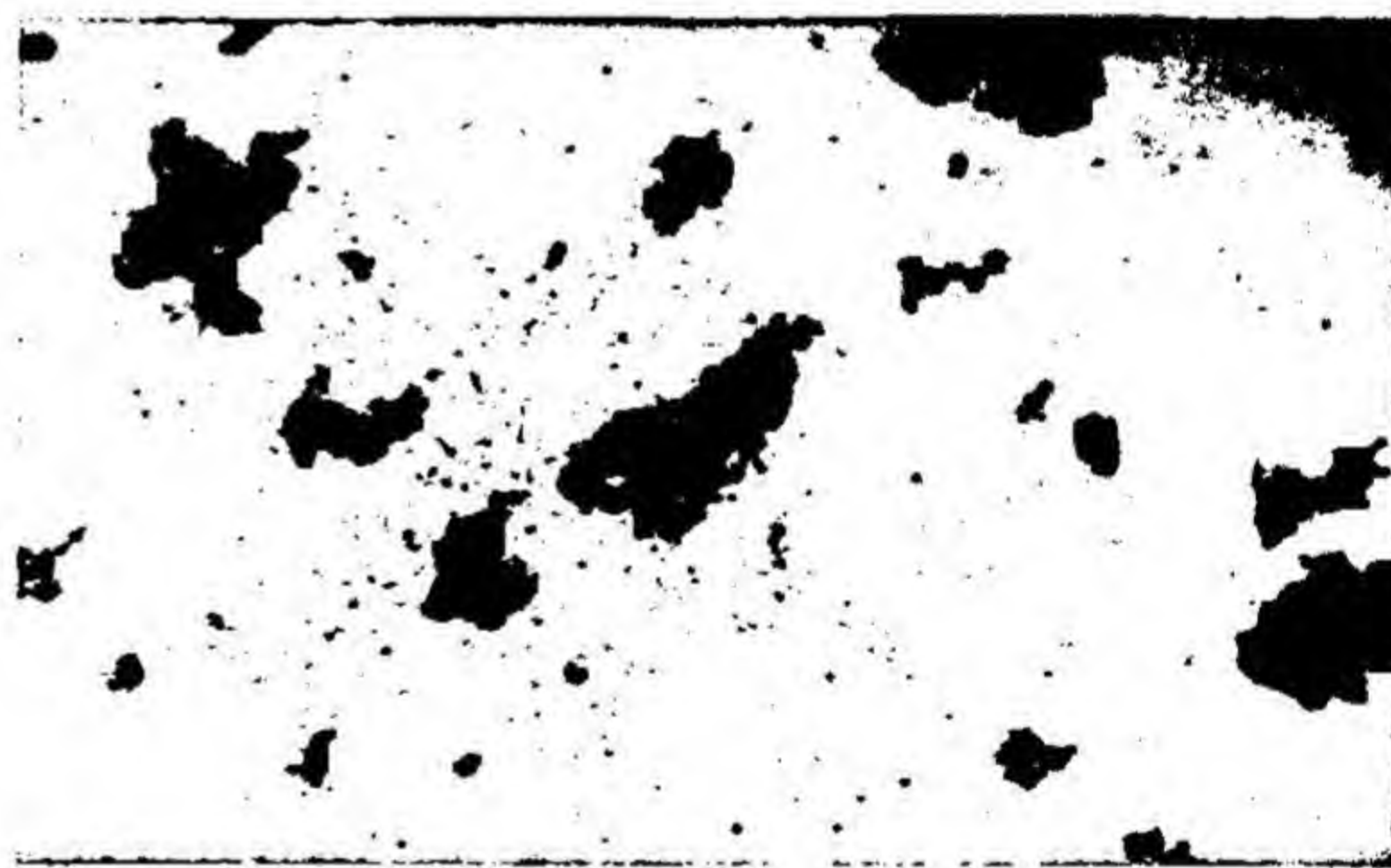
#### *PROCEDURE FOR THE DETERMINATION OF AGGLUTINOGENS*

Place one drop of known A serum (anti-B) and known B serum (anti-A) on the opposite ends of a glass slide. To each drop add one drop of the unknown cell suspension (3 to 5 per cent) prepared as described above. Gently rotate and tilt the slide to insure a thorough mixing of the cell suspension with the serum. Continue this intermittently for approximately 5 minutes and examine each drop with the naked eye for signs of agglutination. A microscopic examination at 50–100X may also be made (Fig. 207).

In forensic examinations, sera from two different sources should be employed in order to have a check on the reliability of the results obtained. It is advisable to use the test tube method since there is less possibility of a nonspecific reaction, such as pseudoagglutination, occurring. Centrifugation is helpful also in that the reaction occurs more quickly. In the case of a weak reaction there is less chance of missing it since the progress of the reaction is accelerated by this mechanical operation.

### Determination of Agglutinins in Fresh Blood

The procedure in this case is the same as that given above for the determination of the agglutinogens except that the reagents now are suspensions of known O, A, and B cells and the serum is the unknown. The serum of the unknown blood (which is to be tested) should not contain any corpuscles, the



**Fig. 207. Microscopic view (100X) of agglutinated blood in the slide method.**



latter being removed by centrifugation. If the unknown serum agglutinated either (or both) of the known A and B cells but not the cells of the control (group O), the nature of the agglutinins in the unknown serum is deduced as follows: If known A cells are agglutinated, the unknown serum contained alpha agglutinin; if known B cells are agglutinated the unknown serum contained beta agglutinin. If neither A or B cells were agglutinated then the unknown serum contained no agglutinins (Table 19).

## 8. GROUPING OF DRY BLOOD STAINS\*

Grouping of dried stains is a much more difficult operation than that of grouping fresh blood. Considerable practice and experience are required before one may feel confident to use one's determinations of the group of a stain as evidence in court. It has been suggested that an individual should have correctly grouped at least fifty known stains before attempting to carry out these tests in medicolegal work.<sup>7</sup> The age of the stain, direct sunlight, extreme temperatures, and other hazards to which the blood may have been exposed are conditions that produce alterations in the agglutinating factors and hence lessen the possibility of success in the grouping of dried stains.

Where possible it is advisable that both the agglutinin and agglutino-gen content of a dried stain be determined since one alone may not be conclusive. However, a negative result — that is, failure to detect an agglutinin or agglutino-gen — cannot be taken to indicate its (or their) absence in the blood originally, for alterations and deteriorations may have taken place which interfere with obtaining a positive reaction. To illustrate how an error might result from neglecting to heed this admonition, suppose that a positive test is obtained only for the agglutinin factor of the blood under examination when it is mixed with known B cells. If one disregards the possibility that the negative A reaction may have been the result of the deterioration of the (anti-A) alpha agglutinin, one would say that the blood tested was a group A. However, all that one should say is that the blood tested may be that of group A or group O; or, to state it in a negative manner, the blood tested could not have come from group B or group AB.

Now, if the test is continued and the agglutino-gen factor determined, one is in a better position to deduce the group of the blood. Let us suppose in the above case that the presence of group specific substance A is demonstrated and B is absent, we may then say with certainty that the blood tested was of group A. If no group specific substance was found, we again may say only that it may be of group O or A.

In general, agglutinins are less stable than agglutinogens. Thus, when the serum factors (the agglutinins) have deteriorated before the laboratory had an opportunity to make the examination, it is necessary to rely upon the results

\* The methods of grouping dried stains, as described here, are those in use in the serological laboratory of the Office of the Chief Medical Examiner of N. Y. City, under the direction of Dr. A. S. Wiener.



obtained from the tests for the agglutinogens. In these cases the results are useful for their eliminative value. For example, in the above hypothetical case if only agglutinin A was found, a suspect could be excluded if the victim's blood was of group B or O. If the victim's blood was of group A, the evidence is unfavorable for the suspect but the laboratory finding would have even greater probative value if the presence of beta agglutinin (anti-A) could also have been demonstrated.

### **Determination of the Agglutinin Factors in Dried Blood**

There are two techniques that can be employed to examine a dried stain for its agglutinin content. If a thin crust of blood can be obtained, a slide method may be used. Such crusts are usually available when the blood is concentrated in a small area instead of having spread out over a large area. If no crust is obtainable, then a test tube-extraction method is employed.

#### ***CRUST-SLIDE METHOD***

A few sq mm of a thin crust (weighing in the region of 0.1 to 1.0 mg), are sufficient for the purposes of this test. Thick crusts are not satisfactory since they cause the cover slip which is placed over the preparation to be raised too high. A scalpel or razor blade is used to dislodge the crust from smooth surfaces such as glass, stone, shoe leather, etc. or to cut it from a fabric in which it is embedded (Fig. 208).

In using the crust method, certain precautions are necessary: cells known to be highly sensitive must be used, the cover glass must be manipulated to break up rouleaux in order to distinguish pseudoagglutination from true isoagglutination, and cells of group O must be used as a control against aggregation produced by other nonspecific causes.

#### **PROCEDURE**

Place two small, thin crusts of blood on the opposite ends of a glass slide. Near the crust on the left side add one or two drops of a 2 per cent suspension of sensitive A<sub>1</sub> cells; near the crust on the right side add one or two drops of a 2 per cent suspension of sensitive B cells. Place a cover glass over each of these preparations so that the liquid comes in contact with the edge of the crust without any air bubbles separating the

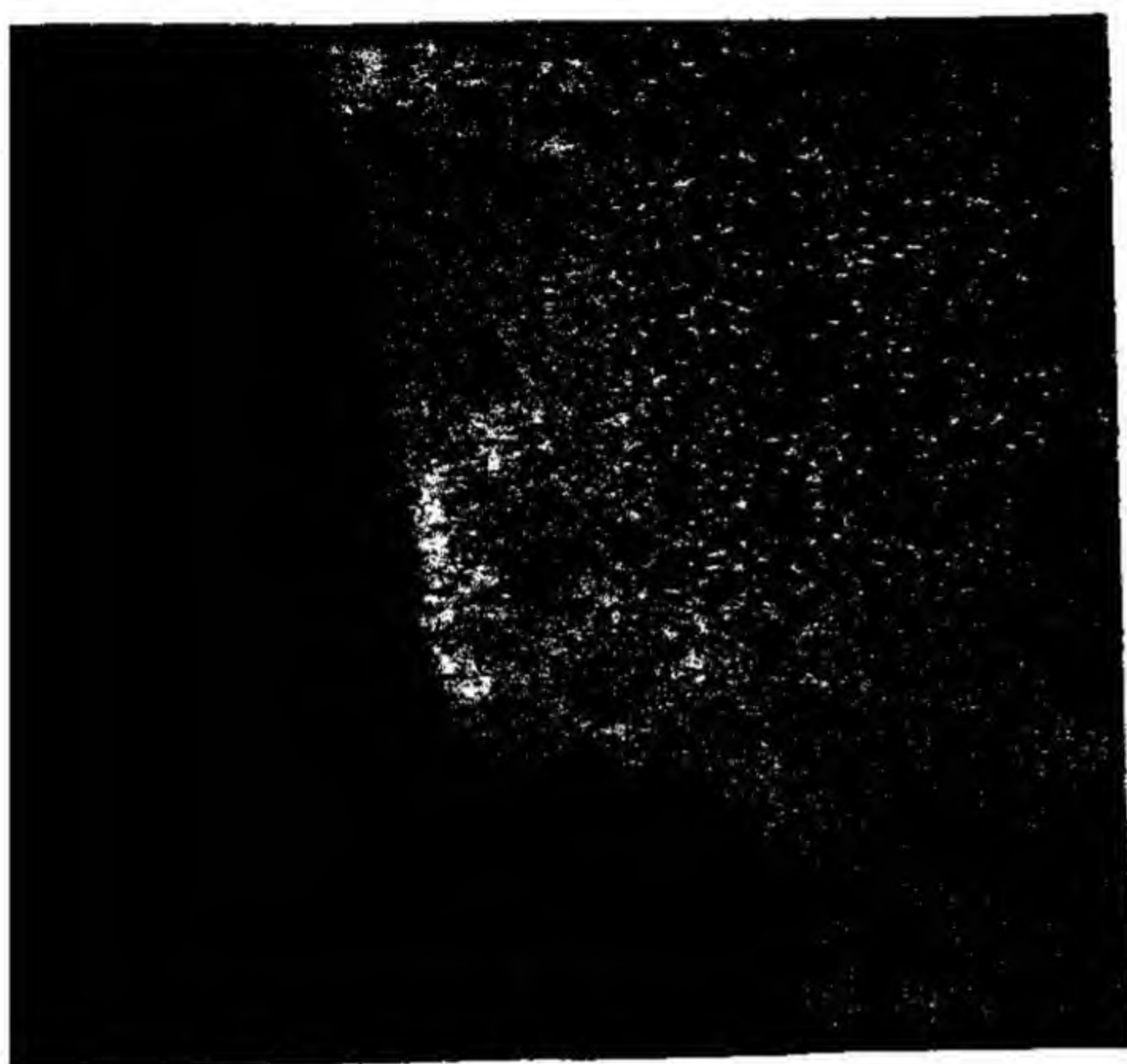


**Fig. 208. Dislodging crusted blood from an axe.**

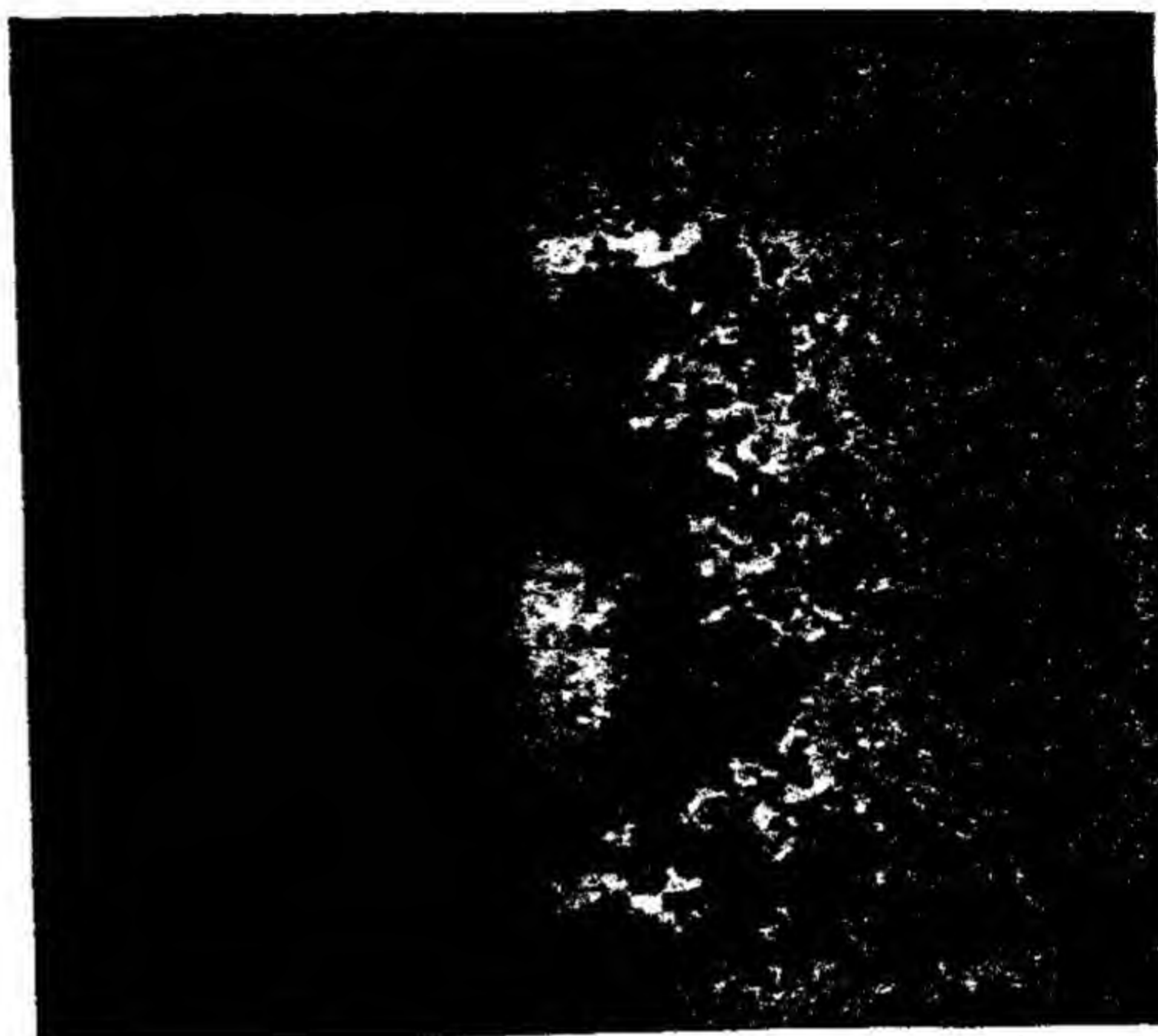


crust from the liquid. Place another crust on a second slide and add a 2 per cent suspension of O cells. A cover glass is placed similarly over this preparation.

After a few minutes examine the preparations under a microscope at medium-power (50–100X) for signs of agglutination (Fig. 209). While making these observations the cover slips may be momentarily subjected to gentle pressure in order to break up any pseudoagglutination formations. If no results are obtained the observations are made from time to time for about 30 minutes in order to avoid missing weak reactions.



(a)



(b)

**Fig. 209. Microscopic view (100X) of agglutination by the crust method: (a) the dark outline on the left is the crust; the free cells are on the right; (b) the cells in the process of agglutination.**

No isoagglutination is possible with O cells, so that if a positive result is observed it indicates that a nonspecific reaction is taking place. In this case it is not possible to differentiate between nonspecific positive reactions with the A or B cells and those attributable to true isoagglutination.

The agglutinins which are found to be present in the stains are used to determine the possible groups to which the stain could or could not have belonged (Table 20). Only positive results are of value since negative reactions may be the result of the deterioration of the agglutinin factor. It should be mentioned that it is possible to have only one of the two agglutinins (alpha or beta) disappear in group O blood.

#### *EXTRACTION-TEST TUBE METHOD*

As an alternative procedure or when no blood crusts are available, a test tube method may be used to determine the agglutinins present in the blood stain.

If the stain is on a solid object, such as a piece of wood or a hammer, the blood is removed by placing drops of saline solution on the stained area. After



several minutes the blood will have dissolved, the solution being picked up with a pipette.

If the stain is on cloth, a portion\* of it is cut out, placed in a test tube, and the minimum amount of saline solution that it is possible to employ is added. A clean glass stirring rod is used to manipulate the cloth in the saline so as to expedite the extraction of the blood and to obtain an extract of the deepest color possible.

The extract is centrifuged to remove any debris that may have found its way into the blood solution during the mechanical manipulations.

#### PROCEDURE

In each of three small test tubes place ten drops of the centrifuged extract solution. To the first tube add one drop of known A<sub>1</sub> cells; to the second tube add one drop of known B cells; to the last tube add one drop of a known O cells. The concentration of the cells that is used depends upon the color of the extract solution and the age of the stain. If the extract is colored fairly deep red or cherry, 2 per cent cell suspensions are employed; if the stain is old or the extract obtained is light cherry or pink in color, 0.5 per cent cell suspensions are employed.

The three tubes are placed in the refrigerator for ten minutes or more, after which they are removed and centrifuged for at least two minutes at 1500 to 2000 rpm. The supernatant liquid of the tube containing the A<sub>1</sub> cells is then poured off and the results determined by adding one drop of saline solution to the tube, after which it is shaken very gently. The supernatant liquids in the tubes containing the B cells, and the O cells, are likewise poured off; one drop of saline is added to each and the tubes are shaken very gently. If the corpuscles are resuspended (as they should be if no nonspecific agglutination has occurred) the test is negative. If the cells have formed clumps that resist breaking up, agglutination has taken place.

A diagrammatic representation of the results possible in each of the three tubes (A<sub>1</sub>, B, O) is shown in Fig. 210; they may be summarized as follows:

#### APPEARANCE AFTER CENTRIFUGING

Tube 1. Cells are on bottom of tube as a sediment, and supernatant liquid has been poured off.

#### POSSIBLE APPEARANCE OF CELLS IN TUBE 1 AFTER ADDING ONE DROP OF SALINE AND SHAKING VERY GENTLY:

Tube 2. Cells are resuspended and the liquid is evenly colored. This is a negative (—) reaction.

Tube 3. Sediment breaks up quite readily but the result is not the same as a clearly negative reaction. This is a very weak (trace) borderline reaction. Such a result is possible if the deterioration of the agglutinin(s) has begun, but has not been completed at the time of the test; it may also indicate a nonspecific reaction.

\* If a limited quantity is available, the whole stained area may have to be used.



Tube 4. Sediment breaks up more easily than in tube 5. This is a weak (+) positive agglutination reaction.

Tube 5. Sediment breaks up slightly. This is a moderate (++) positive agglutination reaction.

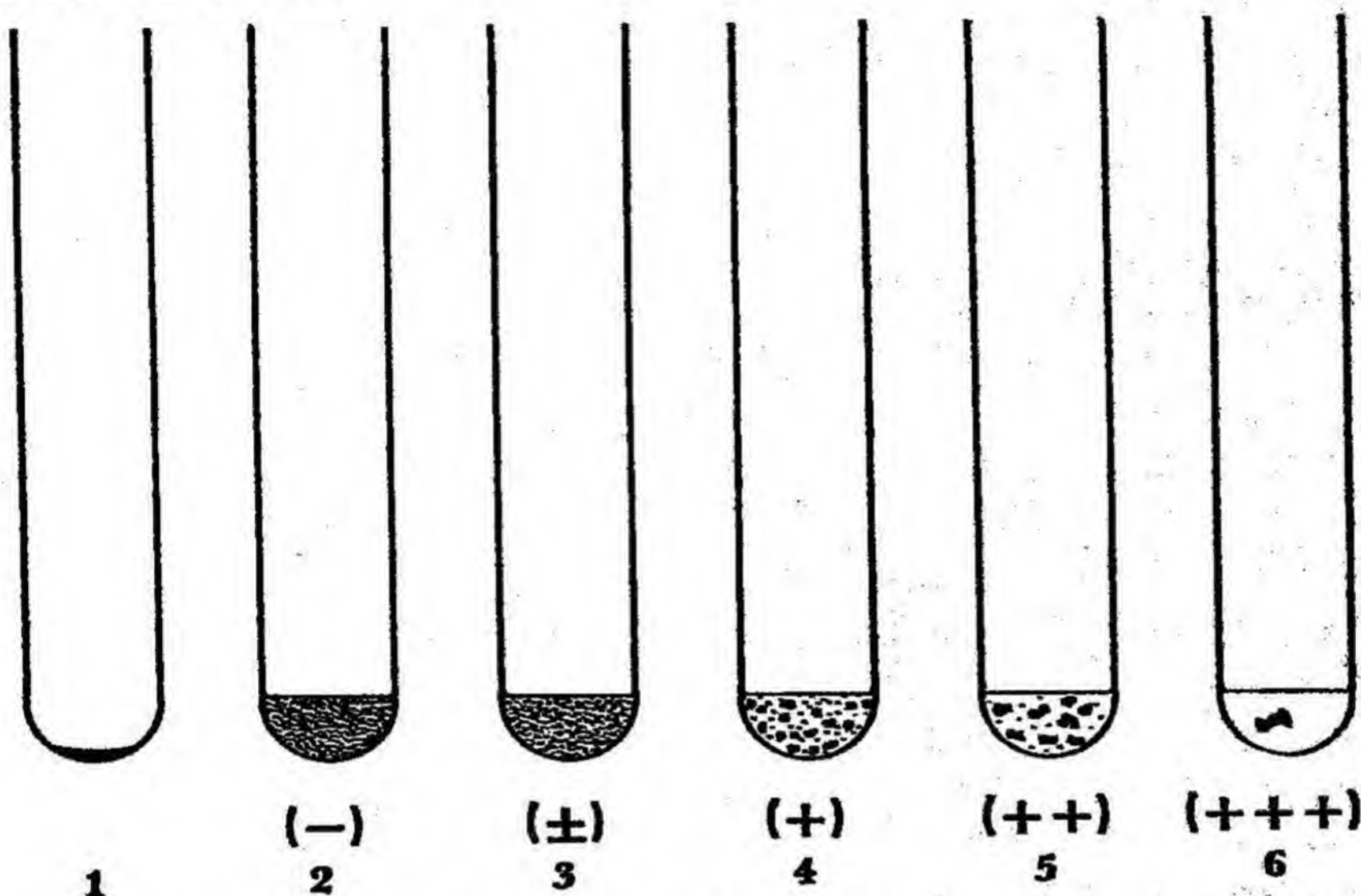


Fig. 210. Diagrammatic representation of the results possible in the test tube method of grouping blood.

Tube 6. Sediment does not break up but floats about as one or two large clumps. This is a strong (+++) positive agglutination reaction.

The interpretation of these results is described in Table 20.

TABLE 20. Interpretation of the Results Obtained in the Tests for Agglutinins

CELLS (ADDED TO CRUST OR EXTRACT)	O (NOTE 1)	A <sub>1</sub>	B	INTERPRETATION
POSSIBLE RESULTS	negative	negative	negative	Group AB (provisional) (Note 2)
	negative	agglutination	negative	Group B (or O with beta deteriorated)
	negative	negative	agglutination	Group A (or O with alpha deteriorated)
	negative	agglutination	agglutination	Group O (absolute)

Note 1 — If any agglutination is obtained with O cells, it is nonspecific; when this happens the results obtained with the A<sub>1</sub> and B cells cannot be used to determine the agglutinins present.

Note 2 — These results are also obtained when the agglutinins have deteriorated with age or because of exposure to unfavorable physical conditions. Thus, this stain could also be A, B or O. The group specific substances must also be determined. Finding both group specific substances, A and B, present identifies the stain absolutely as AB.



### **Determination of the Agglutinin Factors in Dried Blood**

Red blood cells, upon drying, lose their agglutinability owing to the destruction of the free, intact cells as such after drying. A direct test, therefore, can not be made for agglutinogens in dried blood stains. However, the group specific substances retain for long periods their ability to specifically "absorb" or "tie up" their respective agglutinins, alpha and beta. Thus, if a serum of known titer strength is added to an unknown blood stain and if, on retesting, its power to agglutinate has been inhibited or lost, then it may be concluded that the corresponding agglutinin factor was present. Of course suitable precautions and elaborate controls must be employed to exclude possible errors resulting from nonspecific reactions.

### **REAGENTS REQUIRED**

#### **KNOWN CELLS**

Saline suspensions of fresh A<sub>2</sub> cells (2 per cent concentration) and B cells (2 per cent concentration) are required. These cells are necessary for retesting the anti-A and anti-B sera after the unknown stain, substrate and control stains have had an opportunity to absorb the agglutinins.

#### **KNOWN SERA**

Anti-A serum and anti-B serum are required. The titer of the sera should be about 10 to 15 (see sec. 4). It is better to obtain a high titer (ca. 150) serum and to dilute it with saline solution so that its adjusted titer is 10 to 15 rather than to use undiluted serum of which the titer is 10 to 15 originally.

Titer determinations must be made by the same procedure as that which is used in the tests below. For the purpose of determining the group specific substance present in a dried stain, a serum with a satisfactory titer (10 to 15) will agglutinate the known cells (using an open-slide method) in about 5 minutes.

### **CONTROLS REQUIRED**

Known blood of groups O, A<sub>1</sub> and A<sub>2</sub>, and B that have been allowed to dry at room temperature on a clean fabric, are used as control stains. These stains may be prepared as needed; they may then be kept for approximately two months if stored at room temperature.

The group O stain is used to demonstrate that the reagents are agglutinated under the conditions of the test if no antigen, i.e., group substance, is present to absorb or inhibit the activity of the anti-A and anti-B sera. The other groups are necessary to demonstrate that each serum is absorbed when the respective antigens are present.

The substrate or unstained part of the material bearing the stain (fabric, wood, linoleum, paper, etc.) must also be examined to show that no group substance (owing to sweat, saliva, urine, etc.) is present. The unstained portion selected for testing should be quite close to the area where the stain was found.



### PROCEDURE

Arrange twelve small test tubes, each with a capacity of about 2 ml, in two rows of six each. In the first tube in each row place a piece of the stained cloth,\* the size of which is about 1 cm square. In the second tube in each row place an unstained portion of the fabric (the substrate), the size again being approximately 1 cm square. In the remaining tubes in each row place, respectively, pieces of fabric stained with blood of known group O (3rd set of tubes), A<sub>1</sub> (4th set of tubes), A<sub>2</sub> (5th set of tubes), B (6th set of tubes), each piece being about 1 cm square in size.

Anti-A serum is added to each tube in the top row and anti-B serum is added to each tube in the bottom row. The amount of serum that is added to each tube should be the minimum amount possible. That is, considering the nature of the substrate (cloth, paper, relative porosity, etc.) sufficient serum is added so that when the absorption has taken place at least one drop, perhaps two drops, of the serum will be available for retesting.

After the sera have been added to the test tubes, stoppers are inserted and the tubes are then placed in a refrigerator over night or for 24 hours. They are then removed and the sera, which should now be fairly deep red or brown in color owing to the blood dissolved from the stain, are picked up separately. A clean, fresh pipette must be used for each tube. If necessary the sera may be centrifuged to remove any debris that may have accumulated.

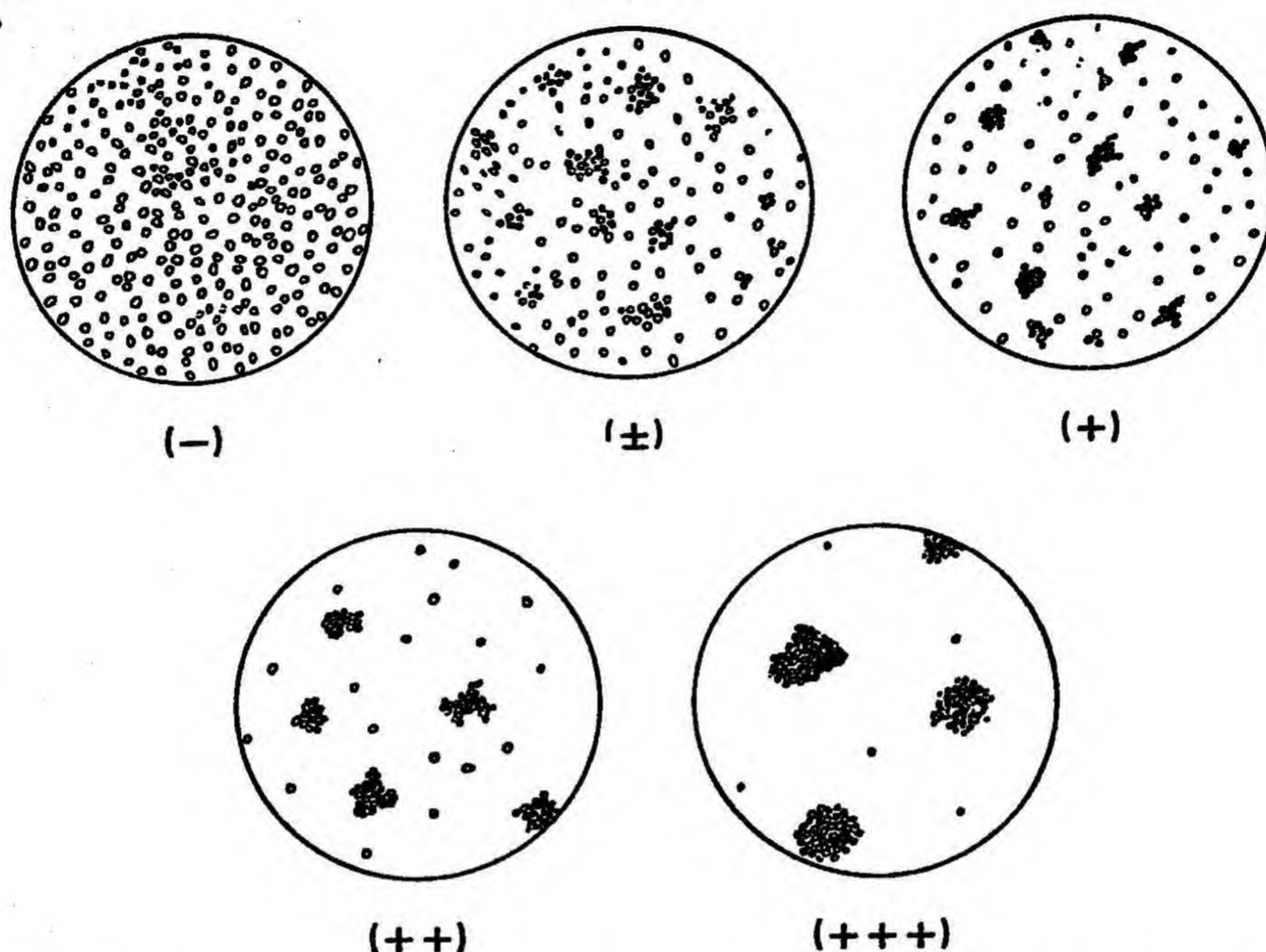
One drop of serum from the first tube of the top row is placed in the first space of a well slide; next, a drop of serum from the second tube of the top row is placed in the second space of a well slide. This procedure is repeated for each of the remaining four tubes of the top row and then again for the six tubes in the bottom row, the relative order of the various sera being maintained at all times.

To the drop of absorbed anti-A serum in each of the wells comprising the top row add one drop of a 2 per cent suspension of known A<sub>2</sub> cells. This procedure is repeated, using, however, a 2 per cent suspension of known B cells, with the anti-B sera in the wells of the bottom row. The slides are then rotated or rocked gently for about five minutes. Rotators which are both suitable and convenient for this operation are available commercially. In addition, they make for reproducible results.

The results may be determined visually, but it is advisable to confirm the findings by further examination under the low-power microscope (ca. 30X). This precaution permits more accurate diagnosis of weak, trace, and negative agglutinations. The results that must be obtained with the control stains, the four possible results that may be obtained with the unknown stain, and their interpretation are summarized in Table 21. A diagrammatic representation of the results that it is possible to observe under the microscope in the well slides is shown in Fig. 211.

\* If the stain is on a solid object such as a hammer or rock, scrape off the blood and powder it. Use about 5 mg of powdered blood in the first tube in each row.





**Fig. 211. Diagrammatic representation of results possible in the slide method of grouping blood.**

The meaning of the symbols used in Fig. 211 is as follows:

(-) A negative reaction. The cells are more or less evenly dispersed when viewed immediately after rocking the slide; on standing the cells settle out, accumulating somewhat in the center of the field but remaining distinctly separate. By gently rotating and moving the slide for a few seconds, the cells again are uniformly suspended.

(±) A very weak borderline reaction. There are some signs of clumping which, however, are not very definite. There are many freely dispersed cells present in the field. On standing, the few large aggregates which were observed may disintegrate. The cells are dispersed somewhat unevenly, but there are no definite clumps. By comparison with the controls, in which more clear-cut reactions should be obtained if the results are to be useful, it may be possible to interpret this as a positive (trace) or negative reaction.

(+) A positive reaction. The cells are clumped in small, but well-defined, aggregates. A small proportion of cells, however, remains freely suspended.

(++) A positive reaction. The cells are well clumped in fairly large aggregates. A few of the cells may remain suspended.

(+++) A positive reaction. The cells are almost completely clumped into a few large aggregates. Practically all of the cells are involved.



TABLE 21. Summary and Interpretation of the Absorption Tests for Agglutinogens

Reagents	Sera employed in absorption test	Anti-A	Anti-B	
	Cells used for retesting sera after absorption	A <sub>2</sub>	B	
Results expected on retesting sera after absorption *				
Controls	Substrate (2nd set of tubes)	Agglutination (sec. 9a)	Agglutination (sec. 9a)	
	Known stain of group O. (3rd set of tubes)	Agglutination	Agglutination	
	Known stain of group A <sub>1</sub> (4th set of tubes)	Negative (sec. 9b)	Agglutination	
	Known stain of group A <sub>2</sub> (5th set of tubes)	Negative (sec. 9b and e)	Agglutination	
	Known stain of group B (6th set of tubes)	Agglutination	Negative (sec. 9b)	
			Interpretation ↓	
Unknown	1st set of tubes	Agglutination (sec. 9d)	Agglutination (sec. 9d)	Group O
	(There are four possible results that may be obtained on retesting the sera after absorption of the unknown stain in the 1st set to tubes. These results may be interpreted as indicated in the third column to the right.)	Negative (sec. 9b and e)	Agglutination (sec. 9c and d)	Group A
		Agglutination (sec. 9c and d)	Negative (sec. 9b)	Group B
		Negative (sec. 9b and e)	Negative (sec. 9b)	Group AB

\* The letters refer to paragraphs in sec. 9 below.

Table 22 is an example of the method of recording the laboratory observations in a typical case:

TABLE 22

MATERIAL EXAMINED	ANTI-A SERUM	ANTI-B SERUM
	+ A <sub>2</sub> CELLS	+ B CELLS
Stained cloth	—	++
Unstained cloth	++	++
O stain on cloth	++	++
A <sub>1</sub> stain on cloth	—	++
A <sub>2</sub> stain on cloth	—	++
B stain on cloth	++	—

Results: Group substance A present in stain; not present in unstained cloth.



## 9. SOURCES OF ERROR IN INTERPRETATION OF GROUPING RESULTS IN DRIED BLOOD STAINS

Equally as important as the technique used in grouping dried blood stains is the interpretation of the results obtained. Many errors are possible. Some pitfalls to be avoided in the interpretation of the varied experimental results that can be obtained are listed below. The lettered paragraphs apply to the parenthetical references in Table 21.

(a) If the preliminary test to determine if the titer of the serum is satisfactory, a (+++) or (++) reaction is obtained (against the known cells which are to be used in retesting the serum after absorption) and if in the actual test the substrate control gives only a (+) or ( $\pm$ ) reaction, then something containing the group substance (sweat, saliva, urine, etc.) is present, and the activity of the serum has been inhibited. Under these circumstances it is not advisable to base any conclusions concerning the group of the stain on the results of the absorption test. If possible another part of the substrate, taken from an area closer to the stain, should be examined to determine if the interfering material is localized or is to be found all over.

(b) If in the preliminary test to determine if the titer of the serum is satisfactory, a (+++) or a (++) reaction is obtained (against the known cells which are to be used in retesting the serum after absorption) and if, in the actual test after the serum has been absorbed by a known or unknown stain, a ( $\pm$ ) result is obtained, it indicates that the group specific substance has reduced the reactivity of the serum.

There are three possible explanations: (1) the stain is old or has been exposed to conditions unfavorable for the preservation of the group substance, (2) the amount of blood in the stain was insufficient in quantity, (3) the serum used was of too high a titer. In the case of the controls, the first two reasons may be eliminated by using freshly prepared, adequate samples. The last possibility may be eliminated by performing another test on another portion of the stain, using serum of lower titer (i.e., by diluting the serum originally used with an equal volume of saline). See (e) below.

Clear-cut negative reactions are required in the controls if the group of a stain is to be based on the absorption test.

(c) If the substrate, known O, and the corresponding known stain in the controls give (+++) or (++) results, a ( $\pm$ ) result with the unknown indicates that the reactivity of the serum has been inhibited. This reduction in titer is attributable to a group specific substance present in the unknown stain.

(d) It must be kept in mind that with an unknown stain a positive result may be obtained owing to the disappearance of the group factor because of age, exposure to undesirable physical conditions, etc. An insufficient quantity of stained material may also account for these results. Identification of an unknown stain as O by the absorption method then is provisional. Group O stains may be identified absolutely by testing for and finding both agglutinins present in the stain (see Table 20).



(e) The  $A_2$  factor is considerably weaker than the  $A_1$ , therefore a ( $\pm$ ) reaction or a marked reduction in the titer of the anti-A serum [say from a ( $+++$ ) to a ( $+$ )] indicates that only a partial removal of alpha agglutinin was achieved. Retesting the stain with serum of lower titer will be useful in confirming the  $A_2$  diagnosis. See (b3) above.

Thus in the grouping of dried stains, to a degree far greater than elsewhere in forensic blood tests, technique, experience, and the condition of the stain (exposure to elements, age, amount, and where found) are of paramount importance. The absence of group specific factors in the stain does not necessarily mean that the blood is that of group O. In particular, the possibility of its being an  $A_2$  must be considered. Similarly, if a stain is found to contain the B factor, consideration must also be given to the possibility of its being an  $A_2B$  group.

### EXERCISES

In order to become sufficiently acquainted with the sensitivity of the various chemical reagents used in the preliminary tests, the substances which give false-positive results, and other conditions which affect the nonspecific chemical tests, the exercises below are suggested. In addition to the benzidine and reduced phenolphthalein, the following nonspecific chemical tests can also be investigated simultaneously:

*Ortho-Tolidin Test* — The reagent is prepared as follows: Add 1 g of ortho-tolidin to 25 ml of glacial acetic acid. A few drops of 3 per cent hydrogen peroxide are added to 2-3 ml of this solution; when this is added to a saline solution of blood a blue color develops.

*Guaiaac Test* — The reagent is prepared as follows: Dissolve 0.5 g of guaiac resin in 30 ml of 95 per cent ethyl alcohol. Filter if necessary.

When this reagent is added to a saline solution of blood and a few drops of 3 per cent hydrogen peroxide added, a blue color results. The solution to be tested must be slightly acidic — glacial acetic acid is used to acidify if necessary — since the blue color does not develop in an alkaline medium.

*Leuco-Malachite Test* — The reagent is made as follows: Dissolve 0.5 g of leuco-malachite green in 50 ml of glacial acetic acid and dilute to 125 ml with distilled water. A few drops of 3 per cent hydrogen peroxide are added to 5 ml of this solution; when this is added to a saline solution of blood a green color which turns dark greenish-blue develops.

1. Prepare each of the reagents mentioned above. Collect in separate test tubes as many of the following materials as possible: urine, nasal secretion, mucus, sputum, saliva, pus, red wine, white wine, fruit juice, vegetable juice, horseradish, laundry bleach, soap, milk, perspiration, potato, potato skin, rust, whole blood, hemolyzed blood (prepared by diluting ordinary blood with water until the opacity disappears). Test each of these substances with each of the reagents. Prepare a list of interfering substances for each reagent. Repeat the tests after boiling a solution of the substances to be tested for about 15-20 seconds; after cooling add the reagents. Are the results the same as before?

2. Prepare a series of test tubes containing blood varying in dilution from 1 part in 1000 parts of saline to 1 part in 1,000,000 parts of saline. Prepare a similar series using ordinary water instead of saline as diluent. Examine 2 ml of these solutions with the preliminary test reagents. Is there any difference in sensitivity of the various reagents?



Does the hemolyzed or laked blood differ with respect to sensitivity from the blood diluted with saline solution?

3. Stain four pieces (each about 3 inches square) of old clothing with blood. Dry one at room temperature; another in a drying oven; expose another to strong sunlight for two days; wash the blood out of the remaining piece. Using the reagents examine each piece of cloth for blood. Do the physical conditions to which an alleged blood stain was exposed affect the results of the chemical tests? Save these clothing pieces for the precipitin tests.

In order to become acquainted with the precipitin test, the following exercises are suggested:

4. The student should stain several old articles of clothing with human blood. After they have dried at room temperature for several hours extract the blood with saline. Dilutions of 1:1000 should be made. Perform the precipitin test, following the procedure outlined in sec. 4.

If only tube no. 4 in Table 17 gives a positive reaction, what conclusion may be drawn? Suppose no tube gives a positive result, what conclusion may be drawn? If tube no. 1 (or 2, 3, 5) in Table 17 gave a positive test what conclusion may be drawn?

5. As an additional study, the student should investigate the effect on the precipitin test for human blood after the stains have been (a) washed with cold water, or (b) with soap, or (c) boiled with water. The effect of age, exposure to sunlight, and artificial heat (oven) may also be investigated. The materials used in exercise 3 can be used.

6. Stains found on leather are troublesome, and it would be profitable to make tests on stains placed on leather. Care must be exercised in adjusting the reaction  $pH$  of the extract.

A similar difficulty is sometimes found in earth stains. Here any lime which is present will interfere unless it is removed by precipitation with carbon dioxide and the precipitate removed by filtration or centrifugation.

In order to group dried blood stains successfully, considerable practice is required. The following exercises will assist the student to master the various techniques required:

7. Have a member of the laboratory clean your ear lobe and a blood lancet (or needle) with alcohol. Prick the dry lobe with the dry lancet (or needle) and obtain a few drops of blood by exerting gentle pressure on the lobe. Draw the blood into a capillary pipette (equipped with a rubber bulb for suction); dilute it according to the directions given in sec. 7. Using known anti-A and anti-B sera, group your blood.

8. Repeat exercise 7, using if possible, persons who are always available and who are willing to volunteer. Keep a record of your results since you may wish to call upon these people to assist in the work of the laboratory by occasionally offering their blood for grouping purposes. In particular, a record of persons with blood of group B should be maintained.

9. Using weak anti-A serum (made so by dilution, if necessary) test simultaneously 20 to 25 bloods of group A. Those bloods which are found to give a weak reaction probably have the  $A_2$  subgroup characteristic, whereas those that give strong reactions probably are of the  $A_1$  subgroup. This hypothesis may be confirmed as follows: Using an anti-A serum that gives reasonably strong reactions with the suspected  $A_2$  cells, mix 2 ml of the anti-A serum with  $\frac{1}{2}$  to  $\frac{2}{3}$  ml of packed (suspected)  $A_2$  cells which have been thrice washed. Allow this mixture to stand at room temperature for  $\frac{1}{2}$  hour. Centrifuge the mixture and remove the supernatant liquid. This serum, i.e., the supernatant, will



usually agglutinate the suspected  $A_1$  cells but will not agglutinate the suspected  $A_2$  cells. If, however, the  $A_2$  cells are agglutinated the procedure above is repeated, using the absorbed serum and a smaller volume of suspected  $A_2$  cells. In this manner it is possible to divide group A blood into subgroup  $A_1$  or  $A_2$ . Keep a record of persons with each of these subgroups since known samples of blood with these subgroup characteristics are required for the examination of dried stains.

10. Using blood of the various groups (O,  $A_1$ ,  $A_2$ , B,  $A_1B$ ,  $A_2B$ ) prepare separate samples of known stains on pieces of cloth (such as old clean sheets or clothing). Be generous in preparing these specimens so that crusts will form and be available for the agglutinin tests. Label each sample only by number. Keep a record in your laboratory notebook of the group of the blood and the number assigned to it. Put these specimens away for two days or so until you have forgotten the groups and numbers. Use these preparations as your unknowns.

Examine the unknown specimens for their agglutinins by both the crust and extraction-test tube methods. Repeat your tests twice. Compare your results with your records which identify the group of the stain. Repeat the tests until you are consistently able to detect the agglutinin present in each stain.

Examine the unknown specimens above for their group specific substances. Repeat your tests twice. Compare your results with your records showing what the group of the stain is. Repeat the tests until you are consistently able to detect the group specific substances present in each stain.

11. After the unknown stains are two weeks old, repeat experiment 10.

12. After the unknown stains are four weeks old, repeat experiment 10.

13. After the unknown stains are six weeks old, repeat experiment 10.

14. After the unknown stains are eight weeks old, repeat experiment 10.

15. After the unknown stains are twelve weeks old, repeat experiment 10.

16. After the unknown stains are twenty weeks old, repeat experiment 10.

Can any conclusions be drawn concerning the age of the blood stain and the degree of success to be expected in grouping tests? Do the agglutinins or the group specific substances disappear first?

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# CHAPTER 32

## SEMEN EXAMINATIONS

### 1. GENERAL

In sex crimes — particularly in rape cases — the laboratory is asked to examine stains, usually on the female's clothing, for evidence of human seminal fluid. In those cases where actual penetration was not accomplished, indications of violence and other conditions of significance to a medical examiner may be absent, so that laboratory semen tests become of critical importance to the investigation.

The descriptions of the method of semen examinations found in some forensic medical texts belie the real difficulties which are frequently encountered in this work. These difficulties are due in part to the variety of stains which are found on the ordinary undergarment, bedsheet, etc., submitted for examination. There are many possible sources of such stains; blood, iron rust, fecal matter, urine, and semen are the most common. The procedure described below attempts to resolve the difficulties somewhat by providing a systematized method of examination.

The first procedure to be studied deals with the relatively rare case in which the alleged seminal fluid is submitted to the laboratory for examination before sufficient time has elapsed for drying. The other procedure, which is the one most commonly required, applies to stains that have dried before the examination is undertaken.

### 2. WET SPECIMENS

Fresh, undried seminal fluid has a characteristic alkaline odor which should be noticeable if the fluid is of seminal origin. The procedure for the examination of moist stains is relatively simple. To prepare the specimen, a drop of the suspected fluid is placed on a glass slide, a drop of distilled water added, and a cover glass is placed over the preparation. A microscopic examination is made using a 43X or 60X objective and a 10X ocular, to detect the presence of spermatozoa (see Fig. 212). It is frequently necessary to stain the preparation in order to locate the spermatozoa. Identification of a spermatozoon is, a present, the only specific test for semen.



### 3. STAINING OF SPERMATOOZOA

Spermatozoa may be stained with several solutions:

#### **Giemsa's Stain**

The constituents of this stain are:

Azur II eosin	3 g
Azur II	0.8 g
Glycerin (C.P.)	125 g
Methyl alcohol (C.P.)	375 g

The methyl alcohol and glycerin are mixed and heated to 60 C; both dyes are added at this point with stirring or shaking until they are in solution. This is permitted to cool and after a day any sediment which has precipitated is removed by filtration. One drop of this stock solution in 1 ml of water is used as the staining solution.

It is convenient to purchase this stain from a commercial supply house rather than to prepare it in the laboratory.

#### **Loeffler's Methylene Blue**

This stain is prepared by adding 3 ml of a saturated alcoholic solution of methylene blue to 10 ml of an aqueous potassium hydroxide solution (1 part KOH to 10,000 parts water).

#### **Carbol Fuchsin**

This stain is prepared by adding 9 ml of a 5 per cent aqueous solution of phenol (carbolic acid) to 1 ml of a saturated alcoholic solution of fuchsin. This is a stock solution which must be diluted 1 part to 5 parts of water.

#### **Procedure**

The preparation on the slide is permitted to dry under a beaker at room temperature, or the drying may be hastened by passing the slide through a column of hot air arising from a Bunsen flame. The spermatozoa are fixed on the glass by quickly passing the slide through a low Bunsen flame three or four times or by standing the slide in (70–80 per cent) methyl or ethyl alcohol for five minutes. The slide is then immersed from one to ten minutes in one of the stains mentioned above. Excess stain is washed off with a gentle stream of distilled water from a wash bottle. The preparation is then dehydrated by immersing the slide in absolute ethyl or methyl alcohol for three minutes. Following this the preparation is cleared; i.e., the opacity that is noticeable in the specimen following the dehydration process is removed, by placing the slide in xylol for a minute or so. A cover slip is placed in position and the slide is examined by means of a microscope at a magnification of 440X (44X objective) or 630X (63X objective). It should be noticed that the rear part of the head of a spermatozoon is, characteristically, more deeply stained (especially with Giemsa's



stain) than the front part of the head or the tail, which frequently do not stain at all (Fig. 212).



Fig. 212. Photomicrograph of stained spermatozoa (ca. 600X).

#### 4. IDENTIFICATION OF SPERMATOZOA

The appearance of a spermatozoon is characteristic, consisting of a head, neck, body, and tail or flagellum. The head and tail only are visible unless the necessary resolution is obtained by the use of a high-power objective. The head has an egg-shaped (ovoid) appearance when viewed flat, but if seen in profile it appears pear-shaped (pyriform). The length of human spermatozoa varies, being in the region of 50 to 70 microns; the head is about  $\frac{1}{10}$  of the total length and is therefore much shorter than the tail.

In the opinion of some cytologists the differential staining of the head

and the recognition of its morphological characteristics are sufficient to identify a spermatozoon even though no tail is appended. It is traditional, however, (particularly in medicolegal writings) to assert that it is necessary to find a complete spermatozoon, intact with head and tail, before a stain may be said conclusively to be of seminal origin. Inasmuch as this historical requirement of an intact spermatozoon is based upon the possibility of confusing certain spores for the head and fibrils or certain bacteria for the tail, the use of the electron microscope suggests a means of resolving these difficulties. Some preliminary investigations, not precisely from a criminalistic point of view, have already been undertaken.<sup>1</sup>

#### 5. DRIED SPECIMENS

##### Color and Stiffness Tests

The first phase of the processing of a fabric for dried semen consists of a general visual inspection for grayish-white (sometimes yellowish) stains which are typical of seminal fluid. The sense of touch is also helpful since dried seminal fluid imparts a starchy stiffness to the portion of the fabric on which it is contained. Sometimes this starched feeling may be the only clue to the possible location of the semen.

##### Ultraviolet Light

Inspection of the material under ultraviolet light is sometimes useful in revealing the location of seminal stains because of their fluorescent qualities.



However, the value of these radiations of short wave length has been overestimated by many writers. To the best knowledge of the authors, ultraviolet light has never been found to be the only means by which it was possible to locate seminal stains when at the same time the other approaches failed to reveal any useful information. Furthermore, the various fluorescent chemicals left on fabrics after several launderings also tend to confuse the task of isolating possible seminal stains. The chief value of an ultraviolet examination lies in limiting the search to a few areas.

### Procedure

Following the physical examination it is possible that several areas may have been found which appear likely to contain seminal fluid. It is advisable to select two or three of the most likely (experience helps here) for the following processing. These instructions apply to the handling of one stained area and obviously should be duplicated for the other suspected stains selected for examination.

The suspected area is cut out of the garment; this is placed in a test tube and sufficient distilled water is added to cover the cloth. The contents of the tube are shaken for 5 to 10 minutes; the cloth is removed and as much fluid as possible is expressed from the cloth. This fluid is added to the fluid in the test tube which is then centrifuged for 5 minutes at 1200 to 1250 rpm. Three-quarters of the supernatant fluid is decanted; the tube is shaken, causing the residue to be resuspended in the remaining fluid. A drop of this suspension is put on a slide, covered with a cover slip and examined microscopically. Another drop of the suspension is put on another slide; this is dried at room temperature or by passing the slide to and fro in the column of hot air arising from a Bunsen burner. This preparation is then fixed and stained in the manner described in section 3.

The following alternative method is preferred by some laboratory workers to the centrifuge technique described above:

- (a) Cut out the stained area — if large, cut out a portion about the size of a nickel — and place on a watch glass, with the stained side down.
- (b) Add distilled water dropwise until the stained area is thoroughly moistened. (Water is used to separate the constituents of the seminal matter from the fabric.)
- (c) Place a small beaker over the watch glass to exclude dust and to prevent excessive evaporation of the solvent. Allow one-half hour for extraction if the stain is of recent origin, and three or more hours if it is several weeks old. During this time the stain must be kept moistened.
- (d) After the necessary time has elapsed the moistened fabric is picked up with tweezers. It is then touched to several clean microscopic glass slides. These may be allowed to dry at room temperature (protected from dust) or they may be dried by slowly passing the slide back and forth in the column of hot air arising from a Bunsen burner.
- (e) Select the last slide prepared and make a Florence test (section 6).



- (f) Place cover glasses on the other slides and examine them under the microscope (60X objective). Of course the first slide examined will be that upon which the fabric was treated with water. The slides may be stained in order to facilitate the location and identification of any spermatozoa which might be present.

As in the case of wet stains, identification of a spermatozoon is at present the only specific test for seminal fluid.

Greene and Burd<sup>2</sup> have developed a technique for examination of cotton fabrics suspected of containing seminal stains. Briefly, the procedure involves dissolving the fibers of cotton in a cuprammonium solution. Safranin is then used to stain the spermatozoa. The results obtained in attempts to extend the technique to include fabrics other than cotton were not promising.

### **Dried Stains on Nonabsorbent Surfaces**

If the stain is on a nonabsorbent surface, the seminal fluid may appear in the form of a crust. In this case it is better to remove a fragment with a scalpel, place it on a glass slide, add a drop of distilled water, and examine the preparation under the microscope. If no spermatozoa are observed immediately, let the fragment steep in the water for several hours, taking precautions to prevent rapid evaporation. Stain the preparation according to the directions given in section 3 and again examine the slide.

## **6. THE FLORENCE REACTION<sup>3</sup>**

In deference to tradition this test is included in the present treatment. The Florence test depends upon a reaction which sometimes takes place when seminal fluid is present. The test, since it is not specific, is no substitute for actual observation of a spermatozoon. It is in an indirect way to some extent confirmatory. No absolute conclusion can be reached from either a positive or negative result. The following are the conclusions which may be drawn:

### **Positive Reaction**

A possibility of the presence of seminal fluid. Since other substances in the body also produce similar crystals with the reagent, the conclusion can be no more specific than this. In general, however, there is a good correlation between positive results in the Florence test and subsequent microscopical identification of spermatozoa in the stain.

### **Negative Reaction**

No conclusions. Interfering substances can prevent the reaction; hence nothing definite may be said. Again, however, there is a good correlation: no positive Florence reaction, no finding of spermatozoa under the microscope.

We see, then, that it is possible to have a positive reaction when seminal fluid is not present and a negative reaction when seminal fluid is present. As the reader has by this time concluded, the test is of limited value.



The composition of the Florence reagent is as follows:

Potassium iodide	1.7 g
Distilled water	30 ml
Iodine	2.5 g

In order to perform the test a portion of the extract is dried on a glass slide and a cover slip added. A drop or two of the Florence reagent is allowed to run under the cover slip and the preparation is observed with a medium-power (100X) microscope for the characteristic brown rhombic crystals which usually form if the stain contains seminal fluid. The reaction is thought to be the result of the choline present in seminal fluid reacting with the iodine-iodide complex to form a periodide of choline.

### EXERCISES

1. Obtain a supply of semen from the medical examiner, coroner or other source. Place a semen stain on several types of fabrics such as muslin or percale sheeting material, silk or rayon undergarment material, etc. Stretch the cloth over a small box or beaker. Examine the fabrics employing the technique outlined for dried seminal stains.

2. One of the fabrics on which semen was placed should be rolled and otherwise mishandled by folding, etc. before the laboratory processing is begun. Record any difficulties which arise in connection with the latter examination. As a result of your findings draw up a paragraph of instructions for detectives to observe when handling fabric material which is to be delivered to the laboratory for a semen examination.

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# CHAPTER 33

## NARCOTICS

Whenever an arrest is made for violation of laws pertaining to narcotics, it is necessary to prove by laboratory analysis that the contraband actually contains a narcotic. For the purposes of law generally, the term *narcotic* is intended to include opium, coca leaves, the various alkaloids which may be derived from either, and cannabis, i.e., the plant *cannabis sativa L.*, the seeds thereof, or the resin extracted from any part of such plant. Any or all compounds, salts, preparations, mixtures, manufactures, or derivatives obtained from the raw material or from their various alkaloids are also defined as narcotics, except derivatives of coca leaves which do not contain ecognine, cocaine, or any substance from which they may be synthesized or made.

The required analyses may be made in the police laboratory by a chemist. The number and types of narcotics which he is usually called upon to identify are perhaps best illustrated by the following list, which represents an average over several years in the New York City Police Laboratory:

Heroin	416
Opium	198
Cannabis Indica	199
Morphine	40
Codeine	5
Cocaine	5
Others	1
Total	864
Narcotics not present	21

Recently a new synthetic drug called *Demerol* has been placed on the market. It, too, has been declared to be a narcotic by many governments; consequently it is contraband, and arrests are made for illegal sales, possession, or use. Occasionally, therefore, it is submitted to the laboratory for analysis. Methods of analysis for this<sup>1</sup> and other narcotics which are even less frequently submitted may be found in the literature and various texts.<sup>2, 3, 4</sup> The following presentation is intended to indicate the procedure that will be most useful in the police laboratory where interest is centered mainly in the analysis of a substance (usually a white powder) for the presence of one of the narcotics listed above.



## 1. GENERAL CHEMISTRY

The term *alkaloid* (which means *like an alkali*) is given to a group of compounds obtained mainly from plant and occasionally from animal sources. They have relatively complex organic structures, are usually white powders, have marked physiological activities, and all contain nitrogen. Many of the alkaloids have been synthesized and are used in medicine. They are usually sparingly soluble in water, but quite soluble in organic solvents. They are rendered water-soluble by salt formation, i.e., as the sulfate, hydrochloride, etc. In the natural state they occur bound to organic acids; for example the opium alkaloids morphine and codeine are combined with meconic acid.

Alkaloids form precipitates with many substances. Three of the most useful precipitants or *alkaloidal reagents* are: (1) Wagner's solution — iodine dissolved in potassium iodide solution; (2) Sonnenschein's solution — phosphomolybdic acid; (3) Mayer's solution — potassium mercuric iodide. Many other reagents are also available; picric and tannic acids, gold, mercuric, and platinum chlorides, heteropoly acids (phosphotungstic, etc.), complex salts (potassium cadmium iodide, sodium nitroprusside, etc.). None of these reagents, however, precipitates all of the alkaloids. Strong bases, such as sodium hydroxide, precipitate practically all the alkaloids with the exception of those with phenolic groups such as morphine; ammonium hydroxide precipitates even the phenolic type.

Qualitative analysis of alkaloids is based on empirical color tests and microscopic examinations of the crystals formed with an alkaloidal reagent. The color tests are conveniently performed on a spot plate. The color changes that take place depend upon the amount of alkaloid and, in general, are best observed when a very small amount is used. A suitable quantity of solid may be obtained in a well of a spot plate from the evaporation of a drop or two of a dilute solution of the alkaloid in a volatile solvent. For certain color tests it is necessary to heat the reactants or to employ a relatively large volume of reagents. Under these circumstances the tests are performed in test tubes.

### Microcrystalline Precipitates<sup>5-10</sup>

For most alkaloids there are a few reagents which yield suitable crystalline precipitates that are highly characteristic. By a microscopic examination of these crystals it is possible to identify the various alkaloids specifically. The procedure employed in the preparation of these crystals is as follows:

A small portion (0.2–0.5 mg) of the purified alkaloid is placed on a glass slide and dissolved in a drop of 0.1 *N* hydrochloric acid. A drop of the reagent is then added and, without stirring or using a cover glass, the results are examined immediately with a microscope using medium power (100X). The crystals may form at once or after a short interval, although it is not uncommon, particularly if one is unfamiliar with the technique, to obtain precipitates that fail to crystallize. For this reason it is important that the directions be followed explicitly and the reagents prepared as directed; otherwise different types of crystals may be obtained.

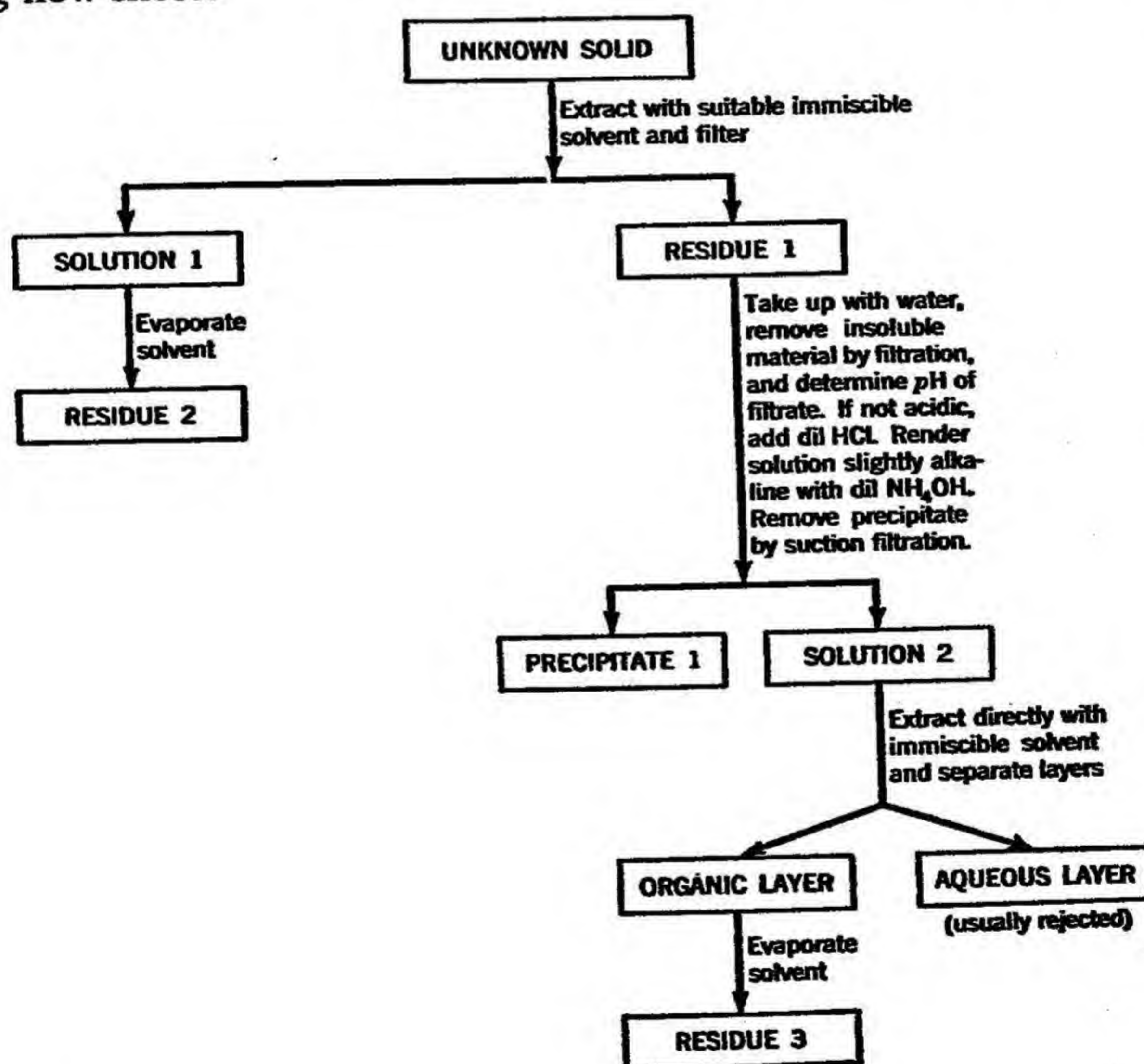


## 2. ADULTERATIONS

When a narcotic arrest is made, the arresting officer frequently is able to ascertain the alleged nature of the drug. At the time the sample is delivered to the laboratory, the arresting officer should be interrogated on this point and the "request for analysis" form (see p. 5) should have a space provided for him to indicate the nature of the sample, i.e., the narcotic alleged to be present.

Various adulterants are commonly employed by the seller to add bulk and increase the weight of the sample, thereby adding considerably to the profit. Some substances reported as having been used for this purpose include chalk, lactose and other sugars, boric acid, sand, ashes, bicarbonate of soda, and various vegetable substances of a resinous nature. Before proceeding with the analysis, then, it is advisable to separate the narcotic from any adulterants that may be present, since it is better procedure to examine a small amount of a pure substance than a large amount of adulterated material.

A general procedure for separating the free alkaloid from its salts and any adulterants that may interfere with its subsequent identification is given in the following flow sheet:



### Procedure

About 1.0 g of the unknown is powdered and mixed with 5 to 7 ml of the organic solvent recommended for the alkaloid alleged to be present. Any insoluble material (residue 1) is separated by filtration and washed twice, each time



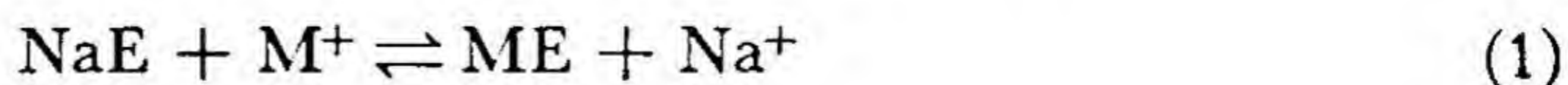
with an additional 3 ml of solvent. The washings are added to the original solution, the solvent is evaporated and the solid recovered (residue 2) is kept for test purposes. The material (residue 1) which failed to dissolve is added to 15 ml of water. After thorough shaking any insoluble material (filler) is removed by filtration, and the filtrate is tested to determine if it is acidic or basic. If acidic, render alkaline with dilute ammonium hydroxide; if basic, the solution is neutralized with dilute hydrochloric acid and then rendered just alkaline with dilute ammonium hydroxide. Any suspension (precipitate 1) that forms is removed, after it has settled, by suction filtration and is kept for test purposes. The aqueous solution is extracted directly with the recommended immiscible solvent; this is repeated twice and the extracts are combined. The solvent is removed by evaporation, and the solid recovered (residue 3) is kept for test purposes. The aqueous solution remaining contains mostly inorganic salts, some filler, and perhaps some alkaloidal traces. Further analysis of this fraction is seldom required. Residue 2, precipitate 1,\* and residue 3, may be combined and further purified by recrystallization, using a solvent different from that used previously.

If the arresting officer was misinformed concerning the nature of the narcotic, it is possible that nothing will be recovered using the procedure described above. In this situation the analyst is faced with an unknown substance, usually in the form of a powder. The next step is to determine if any alkaloid is present in the material. The procedure is as follows:

Dissolve several milligrams of the unknown substance in a few milliliters of 0.1 *N* hydrochloric acid. Filter if necessary, and adjust the acidity of the filtrate until the solution is just neutral. To one or two milliliters of this solution add several drops of Wagner's reagent. If the results are negative repeat the test with another milliliter of the solution but using Mayer's reagent instead. If again no precipitate is formed, it may be concluded that there are no narcotics present. If a precipitate is formed with either of these reagents, the presence of an alkaloid is indicated, but it is probably present in small amounts, or perhaps mere traces are present. Isolation of the alkaloid under these circumstances is quite difficult, if not impossible, by the employment of classical procedures.

With the discovery that certain synthetic organic materials have pronounced and selective absorptive properties over a wide *pH* range, it has become possible to extract cations and anions preferentially from solution by means of an exchange of ions. Many excellent introductory summaries of the information available concerning this process of ion exchange have been published.<sup>11, 12</sup>

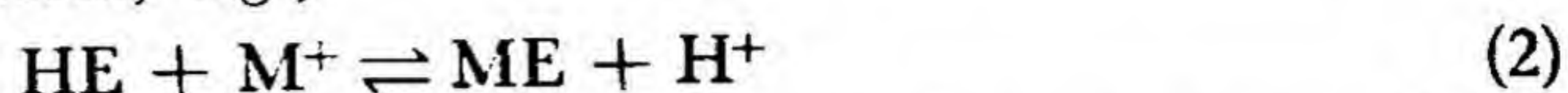
Exchange adsorbents may be classified according to their adsorptive properties, viz., cation exchangers and anion exchangers. In the selective removal of a cation from solution an exchange of ions takes place between the exchanger (NaE) and the cation ( $M^+$ ). The reaction may be depicted as follows:



\* Generally the predominant quantity of alkaloid is found here.

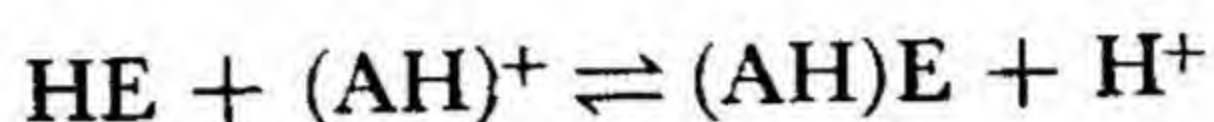


The cation ( $M^+$ ) is recovered as the chloride or hydroxide (and the exchanger regenerated for further use) by passing an excess of sodium chloride or sodium hydroxide over the exchanger (equation 1 reversed). Cation exchangers are also available in a hydrogen form, e.g.,

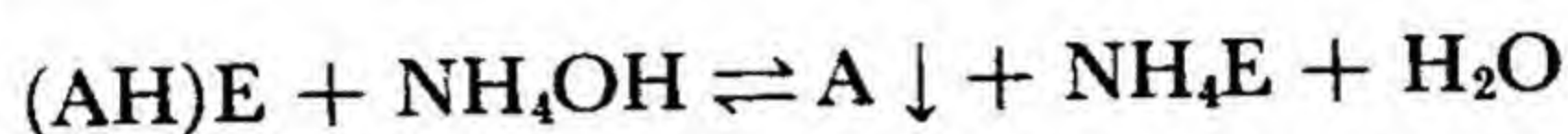


Here, regeneration of the exchanger is effected by passing an excess of acid (usually hydrochloric or sulfuric, ca. 1 to 7 per cent concentration) over it. The cation ( $M^+$ ) is recovered as the chloride or sulfate.

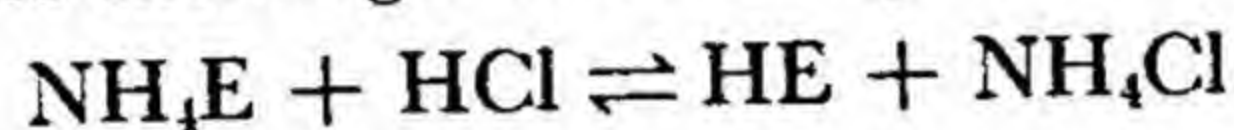
In the case of alkaloids, the extraction is accomplished by passing an acid solution of the alkaloid, i.e., the acid salt of the alkaloid  $(AH)Cl$ , over a cation exchanger:



The alkaloid is recovered by passing an aqueous alkaline solution over the exchanger.



An elution solvent such as chloroform is used to separate the free alkaloid (A) from the exchanger. The exchanger is then regenerated by acid.



The applicability of ion exchange methods as a means of recovering alkaloids has been demonstrated by Sussman<sup>13</sup> and his coworkers. Another investigation has shown that alkaloids which otherwise would have been lost in the mother liquor were recoverable by means of ion exchange.<sup>14</sup> For work on the scale required in the police laboratory the apparatus described by Applezweig is useful.<sup>15</sup>

Following the recovery of any alkaloid by ion exchange, its identity must be determined by more systematic procedures.<sup>16, 17, 18</sup> Since the quantity of material available for analysis is usually quite limited, the manipulative techniques and the apparatus employed by microanalysts will be found useful.<sup>19-24</sup> Recently an x-ray diffraction method has been developed for the identification of micro quantities of various alkaloids.<sup>25</sup>

### 3. REAGENTS

In the analysis of the alkaloids described below, certain reagents are required. It is necessary to state their composition accurately if the results obtained are to be the same as those described in this text, particularly with regard to those reagents used to form the characteristic microcrystalline precipitates. Analytical (reagent grade) chemicals must be used in their preparation.

#### Concentrated Acids and Bases

	<i>Approx. Sp. Gr.</i>	<i>Percentage Comp.</i>
Hydrochloric acid	1.18	35-37
Sulfuric acid	1.84	94-98
Nitric acid	1.42	67-70
Ammonium hydroxide	0.90	27-29



**Dilute Acids and Bases**

Dilute acids and bases are prepared as follows:\*

**Hydrochloric acid**

Dilute 24 ml of concentrated HCl to 100 ml with distilled water.

**Sulfuric acid**

Dilute 6 ml of concentrated  $\text{H}_2\text{SO}_4$  to 100 ml with distilled water.

**Nitric acid**

Dilute 15 ml of concentrated  $\text{HNO}_3$  to 100 ml with distilled water.

**Ammonia**

Dilute 20 ml of concentrated  $\text{NH}_4\text{OH}$  to 100 ml with distilled water.

**Sodium hydroxide**

Dissolve 4.3 g of sodium hydroxide in 100 ml of distilled water.

**Tenth normal hydrochloric acid**

Dilute 9.0 ml of concentrated HCl to 1000 ml with distilled water.

**Froehde's Reagent**

Add 250 mg of sodium molybdate to 50 ml of concentrated sulfuric acid. It may be necessary to heat the acid gently in order to dissolve the solid. This solution is considered to be useful as long as it remains colorless.

**Mandelin's Reagent**

Dissolve 250 mg of ammonium vanadate in 50 ml of cold concentrated sulfuric acid. The solid must be finely ground and considerable shaking may be necessary before complete solution takes place.

**Marmé's Reagent**

Dissolve 5 g of cadmium iodide in 20 ml of water containing 10 g of potassium iodide and heat, if necessary; add water to make 30 ml of solution.

**Marquis' Reagent**

Add 1 ml of 40 per cent formaldehyde solution to 20 ml of concentrated sulfuric acid.

**Mecke's Reagent**

Dissolve 50 mg of selenious acid in 10 ml of concentrated sulfuric acid.

**Oliver's Test**

A drop of dilute sulfuric acid is added to a few particles of alkaloid. A drop of hydrogen peroxide (3 per cent) is then added together with a small piece of copper wire. The solution is made alkaline with dilute ammonia. A positive test is indicated by appearance of a red color that fades to brown on standing.

\* In diluting acids, the acid is added to the water with stirring.



**Wagner's Reagent**

Dissolve 2 g of potassium iodide in 5 ml of water and add 1.3 g of iodine. Shake the solution until the iodine has dissolved, and dilute with water to 100 ml.

**Duquénnois Reagent**

This reagent is prepared as follows:

To 0.5 ml of acetaldehyde in 50 ml of ethyl alcohol add 1 g of vanillin. Shake the mixture until all the vanillin dissolves.

**Mercuric Chloride**

A saturated solution of mercuric chloride is prepared by adding mercuric chloride to 10 ml of distilled water until no more dissolves with shaking. This mixture is then heated until all the solid has dissolved. The solution is then permitted to cool to room temperature. If no solid has precipitated a few crystals of mercuric chloride are added to the solution.

**Chloroplatinic Acid**

One-half gram of chloroplatinic acid ( $\text{H}_2\text{Pt Cl}_6 \cdot 6 \text{H}_2\text{O}$ ) is dissolved in 10 ml of water.

**Chlorauric Acid**

One-half gram of chlorauric acid ( $\text{HAuCl}_4 \cdot 4 \text{H}_2\text{O}$ ) is dissolved in 10 ml of water.

**Inorganic Salts**

Inorganic salts such as ferric chloride, potassium ferricyanide, sodium iodate, etc., are generally used as 10 per cent solutions (approximately) by weight. A dilute solution of these reagents may be prepared by adding two volumes of distilled water to one volume of reagent to make (approximately) a 3 per cent solution.

**4. OPIUM**

Opium is obtained from the plant, *Papaver somniferum* L. or "sleep-bearing" poppy. It varies in quality, appearance, and composition according to its mode of preparation. Over twenty-five different alkaloids and other substances have been isolated from this narcotic.<sup>1</sup> One of these substances is meconic acid, a compound found in nature associated with opium. Fortunately, this acid occurs nowhere else and is peculiar to opium. Therefore, to identify opium the analyst must detect meconic acid and one of the alkaloids present in opium, morphine being the one usually selected for this purpose.

**Physical Characteristics**

1. Opium possesses a characteristic odor. When the odor is faint, pulverization of the material assists in its detection; burning a small particle also may be helpful.



2. Opium is usually dark brown in color. If the substance has been dried it is likely to be lighter; a poor adulterant may also change the color of the substance.

### Chemical Tests

#### *DETECTION OF MECONIC ACID — RIGOROUS METHOD*

To isolate this acid, a 15 per cent solution (by weight) of lead acetate is added, drop by drop, to a warm aqueous solution of the opium until the precipitation is complete. The test tube is allowed to cool and the precipitate of lead meconate is removed by filtration and washed once or twice with water. It is then transferred to a test tube, and hydrogen sulfide is passed through. Lead sulfide is precipitated and meconic acid is liberated. The lead sulfide is removed by filtration and the meconic acid is recovered by extraction with ether. The residue which remains after the evaporation of the ether is tested as follows:

(a) A small portion of the solid is placed on a white tile plate, or in a small test tube. A drop or two of water, slightly acidified with dilute nitric or dilute sulfuric acid is added. To this solution a drop of a 1 per cent solution of ferric chloride is added. If the solid is meconic acid a deep red color will develop. This color is not discharged by adding hydrochloric acid and heating slightly (hence different from ferric acetate), nor is the solution decolorized by mercuric or gold chloride (hence different from ferric thiocyanate). The red color may be bleached with stannous chloride and regenerated with potassium nitrite.

(b) Add a drop of Mandelin's reagent to a small portion of the solid acid. A characteristic purple to deep blue color develops; this gradually fades on standing.

(c) Characteristic crystals are obtained as precipitates when potassium ferrocyanide, barium chloride, or calcium chloride solutions are added to a solution of the acid.

A small portion (0.2 mg) of the acid is placed on a microscope slide and dissolved in a drop of water. A drop of one of the above reagents (10 per cent solution by weight) is added. The slide is examined under a microscope with medium power (100X).

#### *DETECTION OF MECONIC ACID — SIMPLIFIED METHOD*

Frequently it is unnecessary to isolate meconic acid as such, the test for its presence being performed directly on a piece of opium.

A particle of the suspected opium is placed on a tile plate in a drop of dilute nitric acid. A drop of a 1 per cent ferric chloride solution is then added. If red streaks spread throughout the liquid, the presence of meconic acid is indicated.

#### *DETECTION OF MORPHINE — SIMPLIFIED METHOD*

As mentioned above, morphine is one of the many alkaloids present in opium and it is necessary to demonstrate its presence in a substance alleged to be opium. The Marquis reagent is generally used to detect morphine for this



purpose. A purple-violet color develops when this reagent is added to a small particle of opium. If a satisfactory color does not develop with the solid opium, a mixture of chloroform (75 per cent by volume) and isopropyl alcohol (25 per cent by volume) may be used to extract the morphine. The solvent is evaporated over a water bath and a particle of the residue is examined with the Marquis reagent. If morphine is present a purple-violet color develops.

## 5. MORPHINE

Morphine is obtained from opium and is one of the principal alkaloids present in the dried exudate of the poppy capsule. The morphine content varies from 5 to 18 per cent. Together with other evidence, its detection is necessary as a part of the examination of a substance for opium. The solubility of morphine in strong alkali (owing to its phenolic group) provides a means for its separation from the other alkaloids present in opium.

To extract morphine from an unknown substance in which it is alleged to be present, the procedure described in sec. 2 may be used. A solvent which is suitable for the extraction of morphine is a mixture of chloroform (75 per cent by volume) and isopropyl alcohol (25 per cent by volume). The morphine recovered at the various stages in the procedure may be further purified by recrystallizing, using ethyl alcohol (95 per cent) as the solvent.

### Spot-Plate Tests

To perform these tests a small particle of the solid is placed on a tile plate, the indicated reagent is added and the colors which develop are noted.

REAGENT	OBSERVATION
<i>Marquis</i>	A purple-violet color develops immediately. The color becomes more intense on standing.
<i>Froehde</i>	A purple-red color develops immediately. On standing, the color deepens and takes on a somewhat brownish appearance in the center of the drop and a greenish-yellow at the edge; after several minutes the color becomes greenish-blue. If a large quantity of morphine is used the color changes from purple-red to brownish and then to brownish-green.
<i>Mecke</i>	A blue color that passes rather quickly to green is observed. On standing this deepens to olive green.
<i>Nitric Acid (conc)</i>	A red-orange changing to yellow-orange.
<i>Ferric Chloride (10%)</i>	A blue-green. This color may be destroyed by heat, acid, or alcohol.
<i>Oliver's Test (see sec. 3)</i>	A strong red-orange color develops immediately.



## Test-Tube Methods

### *IODIC ACID TEST*

To 1 ml of a dilute aqueous solution of morphine add 1 ml of a mixture containing equal parts of a 5 per cent potassium iodate ( $\text{KIO}_3$ ) solution and dilute sulfuric acid. In the presence of morphine a brown color develops. Add 5 drops of chloroform and shake the test tube vigorously. The chloroform layer turns a violet color as a result of the iodine formed by the reduction of the iodate by the morphine present. This is a test for a reducing substance and is not specific for morphine but at the same time it will serve to distinguish morphine from heroin and codeine.

### *PRUSSIAN BLUE TEST*

To a dilute sulfuric acid solution of morphine in a test tube add a few drops of dilute (3 per cent) potassium ferricyanide solution and a few drops of 10 per cent ferric chloride solution. A blue color develops if morphine is present, owing to its reducing action on the ferricyanide. The ferric chloride reacts with the ferrocyanide produced to form Prussian blue. This is a test for a reducing substance and is not specific for morphine. Heroin gives similar reaction but only after heating and standing for a time. Codeine develops a green color under these conditions.



Fig. 213. Morphine with Marmé's reagent.

### *NITROUS ACID TEST*

To a few drops of dilute hydrochloric acid in a small test tube add a particle of morphine, then add several drops of a dilute (3 per cent) solution of sodium nitrite. After a yellow-green color has developed, the solution is rendered alkaline with sodium hydroxide. In the presence of morphine the solution turns



d. This color is discharged with acid and restored with alkali. This test is not specific but since heroin and codeine do not respond, it serves to distinguish among these narcotics.

### Crystalline Precipitates

#### *MARMÉ'S TEST*

On a microscope slide dissolve about 0.5 mg of the alkaloid in a drop of .1 *N* hydrochloric acid and add one drop of Marmé's reagent. Without stirring or placing a cover slip over the preparation, examine it under a microscope with medium power (100X). Compare results with those in Fig. 213. At first the precipitate may be amorphous, but on standing it should crystallize.

#### *WAGNER'S TEST*

Repeat as in Marmé's test except that Wagner's reagent is used. Compare results with those in Fig. 214.

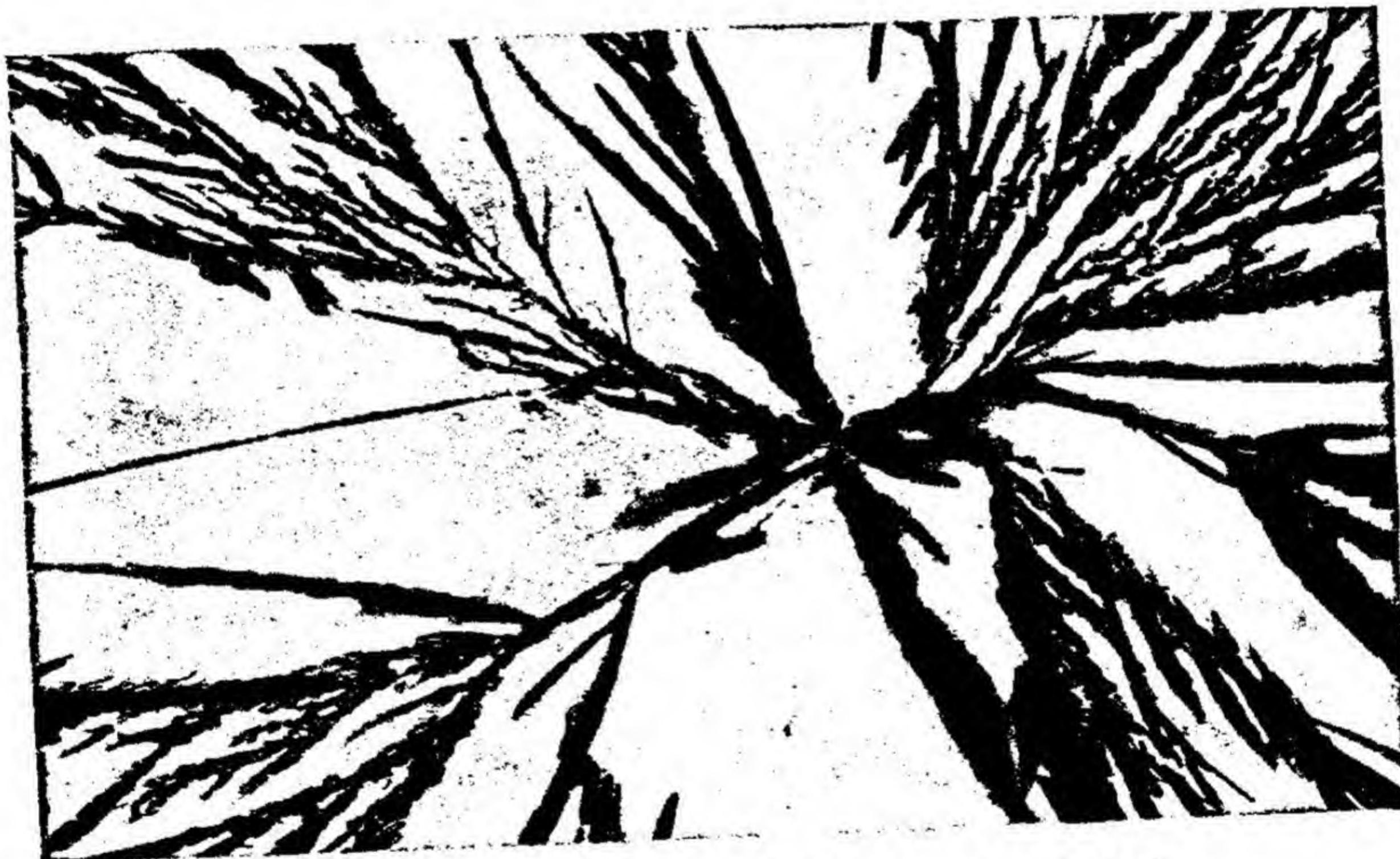


Fig. 214. Morphine with Wagner's reagent.

## 6. CODEINE

Codeine is found in opium (particularly the Persian variety) in quantities varying from 1 to 3 per cent. This substance is the methyl ether of morphine and is usually prepared synthetically by the methylation of morphine. It is peculiar among the alkaloids of opium, particularly differing from morphine in that it is relatively soluble in water (over 1 per cent at room temperature). It is almost insoluble in strong alkali; whereas morphine is easily dissolved under these conditions.

To extract codeine from an unknown substance in which it is alleged to be present, the procedure described in sec. 2 may be used. Solvents which are suitable for the extraction of codeine are chloroform and benzene. The codeine recovered at the various states in the procedure may be further purified by reprecipitating using water as the solvent.



**Spot-Plate Tests**

REAGENT	OBSERVATION
<i>Marquis</i>	A purplish-violet color which rapidly becomes very intense.
<i>Froehde</i>	A yellowish-green, olive green, finally turning blue in about 5 minutes.
<i>Mecke</i>	A green, rapidly turning to dark green, and finally turning greenish-blue or blue within a short time.
<i>Nitric Acid</i> (conc)	An orange color changing rapidly to yellow.
<i>Ferric chloride</i> (10%)	No color change.
<i>Oliver's Test</i> (see sec. 3)	No color develops.

**Test-Tube Methods**

To 2 ml of concentrated sulfuric acid in a test tube add a few particles of codeine. Shake the test tube until the solid dissolves and add a few drops of a 1 per cent solution of ferric acetate and a few drops of dilute aqueous formaldehyde solution (1 part in 10,000). A blue-violet color develops in a short time. This is not a specific reaction for codeine. Morphine and heroin also react under these conditions but the colors which develop differ.

Add 10 mg of codeine to 2 ml of water containing a few drops of 10 per cent potassium ferricyanide solution, then add one or two drops of ferric chloride solution. A green color develops if codeine is present. Under these conditions morphine gives a blue color (Prussian blue) while heroin does not react immediately, but only after standing for a time.

To 10 mg of codeine in 5 ml of concentrated sulfuric acid add one drop of a 10 per cent solution of ferric chloride. On heating, the solution turns blue; with the addition of a drop of concentrated nitric acid it changes to red. Morphine and heroin react similarly.

To a particle of codeine dissolved in 2 ml of concentrated sulfuric acid add a few drops of 10 per cent sucrose solution. A reddish-brown color develops which on very gentle warming turns to deep red. This is not specific for codeine. Morphine and heroin react similarly.

**Crystalline Precipitates**

**MARME'S TEST.** On a glass slide dissolve 0.5 mg of codeine in 1 drop of 0.1 *N* hydrochloric acid. Add a drop of Marmé's reagent and examine under a microscope with medium power (100X), without stirring or placing a cover glass over the preparation. Compare results with those in Fig. 215. At first the precipitate may be amorphous but on standing it should crystallize.

**WAGNER'S TEST.** Follow directions as given in Marmé's test except that the Wagner reagent is used. Compare results with those in Fig. 216.





(a)



(b)

Fig. 215. Codeine with Marmé's reagent: (a) Stage 1; (b) Stage 2.

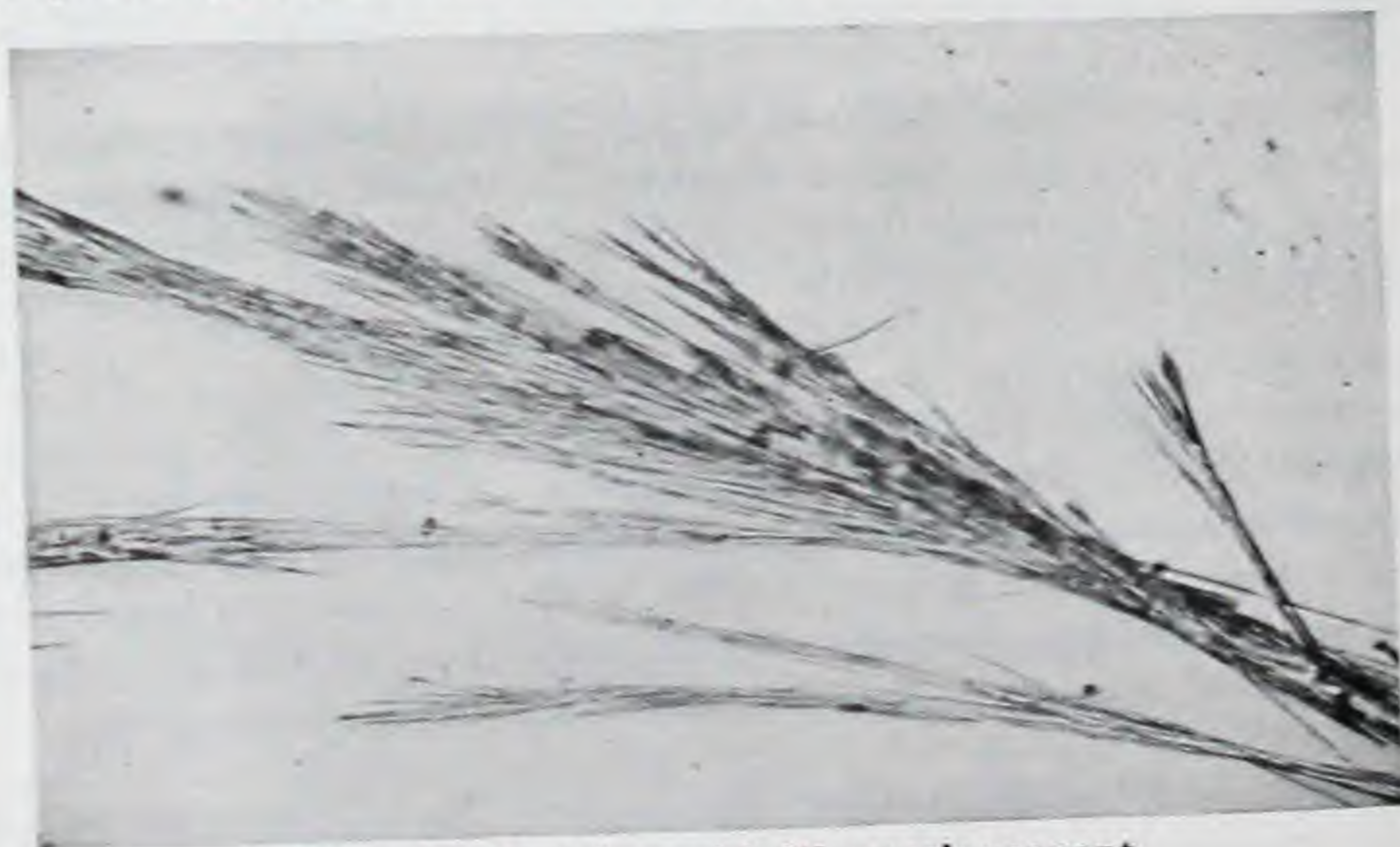


Fig. 216. Codeine with Wagner's reagent.



## 7. HEROIN

Heroin is not a naturally occurring alkaloid, being made synthetically by the acetylation of morphine. Heroin is the diacetyl derivative of morphine.

As a drug of addiction it is particularly dangerous since no hypodermic needle is required for its administration. It is sufficient merely to sniff the drug in order to have it absorbed by the body. When sold illicitly, it is frequently adulterated with sodium carbonate, chalk, or other cheap white powder.

To extract heroin from an unknown substance in which it is alleged to be present, the procedure described in sec. 2 may be used. A solvent which is suitable for the extraction of heroin is chloroform. The heroin recovered at the various stages in the procedure may be further purified by recrystallizing, using a mixture of alcohol (75 per cent by volume) and water (25 per cent by volume) as the solvent.

### Spot-Plate Tests

REAGENT	OBSERVATION
<i>Marquis</i>	A reddish-purple color develops.
<i>Froehde</i>	A violet-purple color develops immediately. On standing it turns purplish-brown.
<i>Mecke</i>	Light green rapidly changing to a darker greenish-blue.
<i>Nitric Acid</i> (conc)	A faint yellow color, which turns a green that becomes more intense on standing.
<i>Ferric Chloride</i> (10%)	No reaction.
<i>Oliver's Test</i> (see sec. 3)	A red-orange color.

### Test-Tube Methods

#### PRUSSIAN BLUE TEST

To a dilute sulfuric acid solution of heroin in a test tube add a few drops of a 10 per cent potassium ferricyanide solution and a few drops of a 10 per cent ferric chloride solution. Warm gently and allow the test tube to stand. After the heroin has had time to hydrolyze, a blue color will develop. This differs from morphine which gives the blue coloration immediately, and codeine, which gives a green color.

#### DETECTION OF ACETYL GROUPS

Several particles of heroin are added to a test tube containing 1 ml of concentrated sulfuric acid and 1 ml of ethyl alcohol. Acetic acid is formed by the hydrolysis of the heroin, and in the presence of concentrated sulfuric acid it reacts with the ethyl alcohol to form an ester (ethyl acetate) which has a characteristic odor. This is not specific for heroin, but neither morphine nor codeine react in this manner.



## Crystalline Precipitates

### *CHLOROPLATINIC ACID*

On a microscope slide dissolve a small portion (0.5 mg) of the alkaloid in a drop of 0.1 *N* hydrochloric acid and add a drop of chloroplatinic acid. When the slide is nearly dry, examine under a microscope with medium power (100X) and compare results with those in Fig. 217.

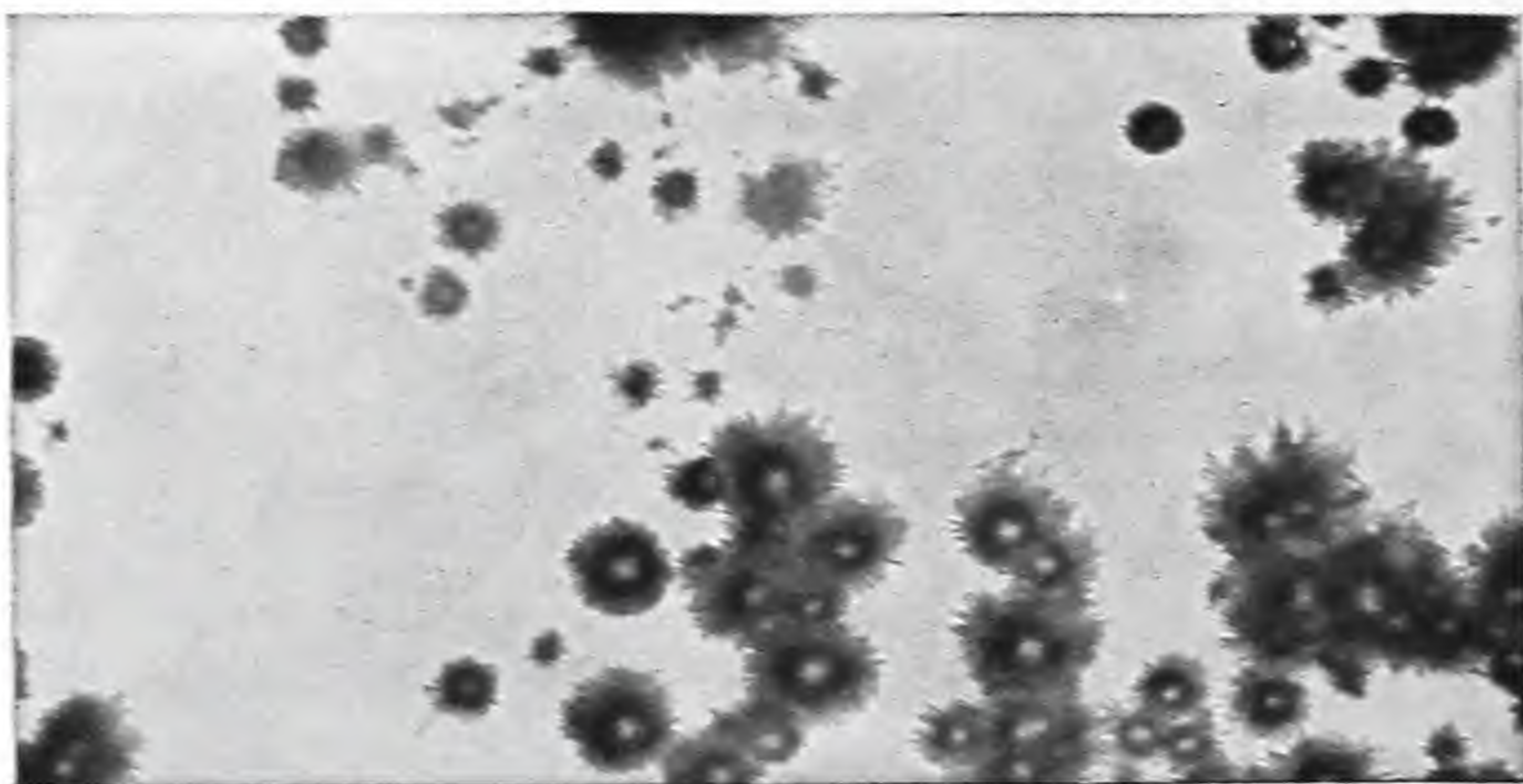


Fig. 217. Heroin with chloroplatinic acid.

### *MERCURIC CHLORIDE*

Dissolve a small portion (0.2 mg or less) of the alkaloid in one drop of 0.1 *N* hydrochloric acid on a glass slide and add one drop of the mercuric chloride reagent. Compare results with those in Fig. 218.

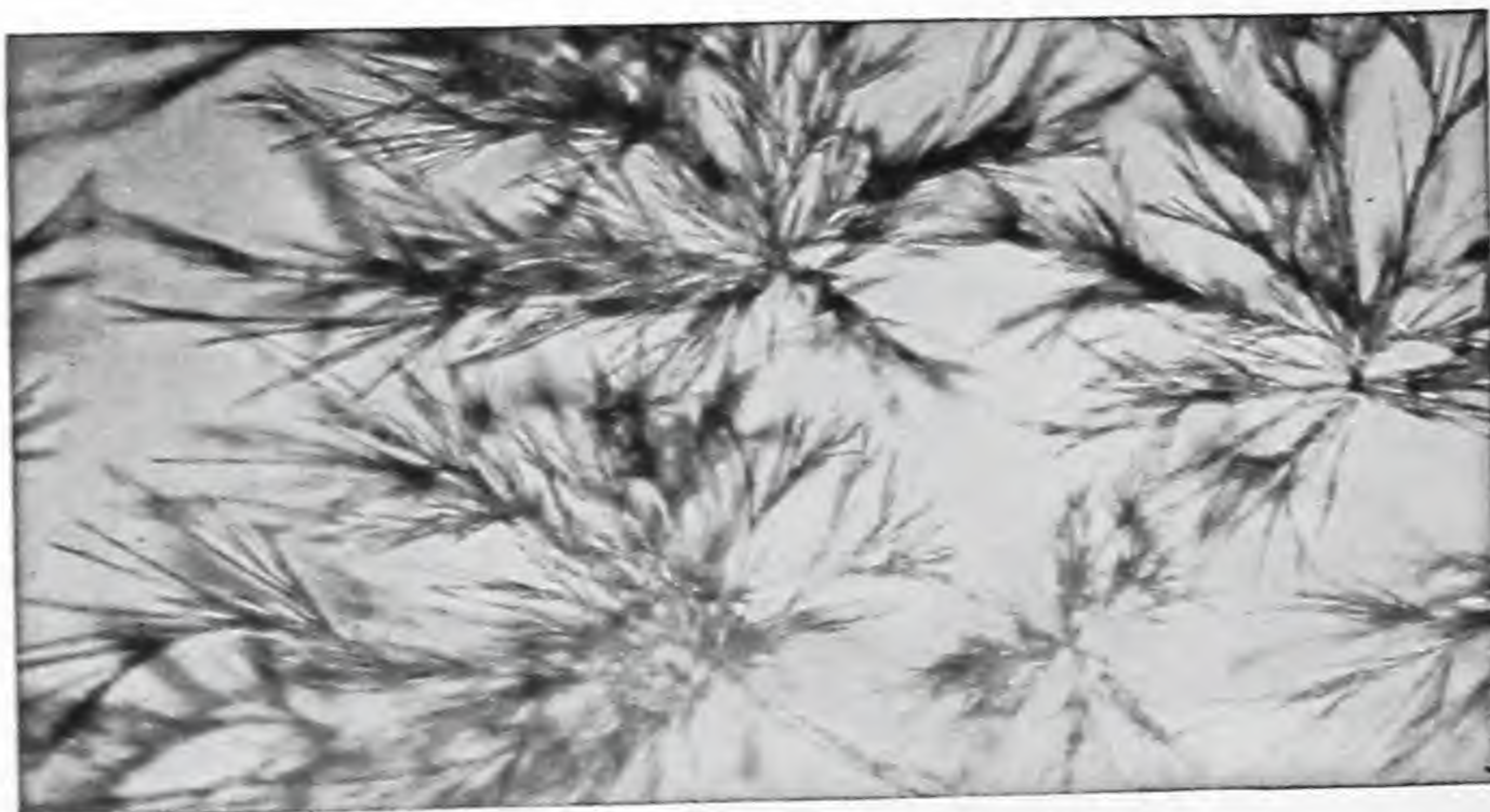


Fig. 218. Heroin with mercuric chloride.



## 8. COCAINE

Cocaine is a natural product obtained by extraction from the leaves of the coca shrub. The drug is usually encountered as the hydrochloride salt, the crystals of which are a sparkling white. It is therefore usually difficult to find a suitable cheap adulterant for cocaine.

To extract cocaine from an unknown substance in which it is alleged to be present, the procedure described in section 2 may be used. A solvent which is suitable for the extraction of cocaine is ether. The cocaine recovered at the various stages in the procedure may be further purified by recrystallizing, using a mixture containing ethyl alcohol (60 per cent by volume) and water (40 per cent by volume) as the solvent.

There are no spot-plate color tests for this narcotic.

### Test-Tube Methods

#### *POTASSIUM PERMANGANATE TEST*

Add 0.01 g of cocaine to 0.5 ml of dilute hydrochloric acid in a small test tube; if necessary shake the tube until the solid is dissolved. To this solution add drop by drop, a saturated solution of potassium permanganate. Observe the violet crystalline precipitate which is formed when cocaine is present. Permanganate oxidizes almost all other alkaloids and cocaine substitutes under these conditions, and in so doing is decolorized. This is a useful test in distinguishing among cocaine and the other alkaloids in which a police chemist is ordinarily interested.

#### *CHROMIC ACID TEST*

To 0.01 g of cocaine in a test tube add 0.5 ml of water and a few drops of dilute hydrochloric acid. The addition of one drop of an 8 per cent solution of potassium dichromate (acidified with 5 ml of dilute hydrochloric acid per 100 ml of dichromate) causes a yellow precipitate to form. The precipitate dissolves if the tube is shaken. The addition of a few more drops of dichromate produces a permanent heavy yellow-orange precipitate of cocaine chromate.

#### *DETECTION OF BENZOYL GROUP*

Gently warm 1 ml of concentrated sulfuric acid and several particles (over 0.2 gm) of cocaine together in a test tube. Allow the tube to cool and dilute (*exercise care!*) the contents, by adding water dropwise; during this process keep the tube partially immersed in cold water. At the completion of the dilution the odor of methyl benzoate may be noticed, while on cooling and standing a white precipitate of benzoic acid will have formed. The benzoic acid is recovered by extraction with ether. The residue left following the evaporation of the ether is esterified by heating it with 1 ml of ethyl alcohol in a tube with a few drops of concentrated sulfuric acid. The characteristic odor of an ester (ethyl benzoate) develops.



## Crystalline Precipitates

### CHLOROPLATINIC ACID

On a glass slide dissolve a small portion (0.2 mg) of the solid in one drop of 0.1 *N* hydrochloric acid and add one drop of chloroplatinic acid reagent. Without stirring or covering the preparation with a cover glass, examine the results immediately under a microscope with medium power (100X). Compare the results with those in Fig. 219.

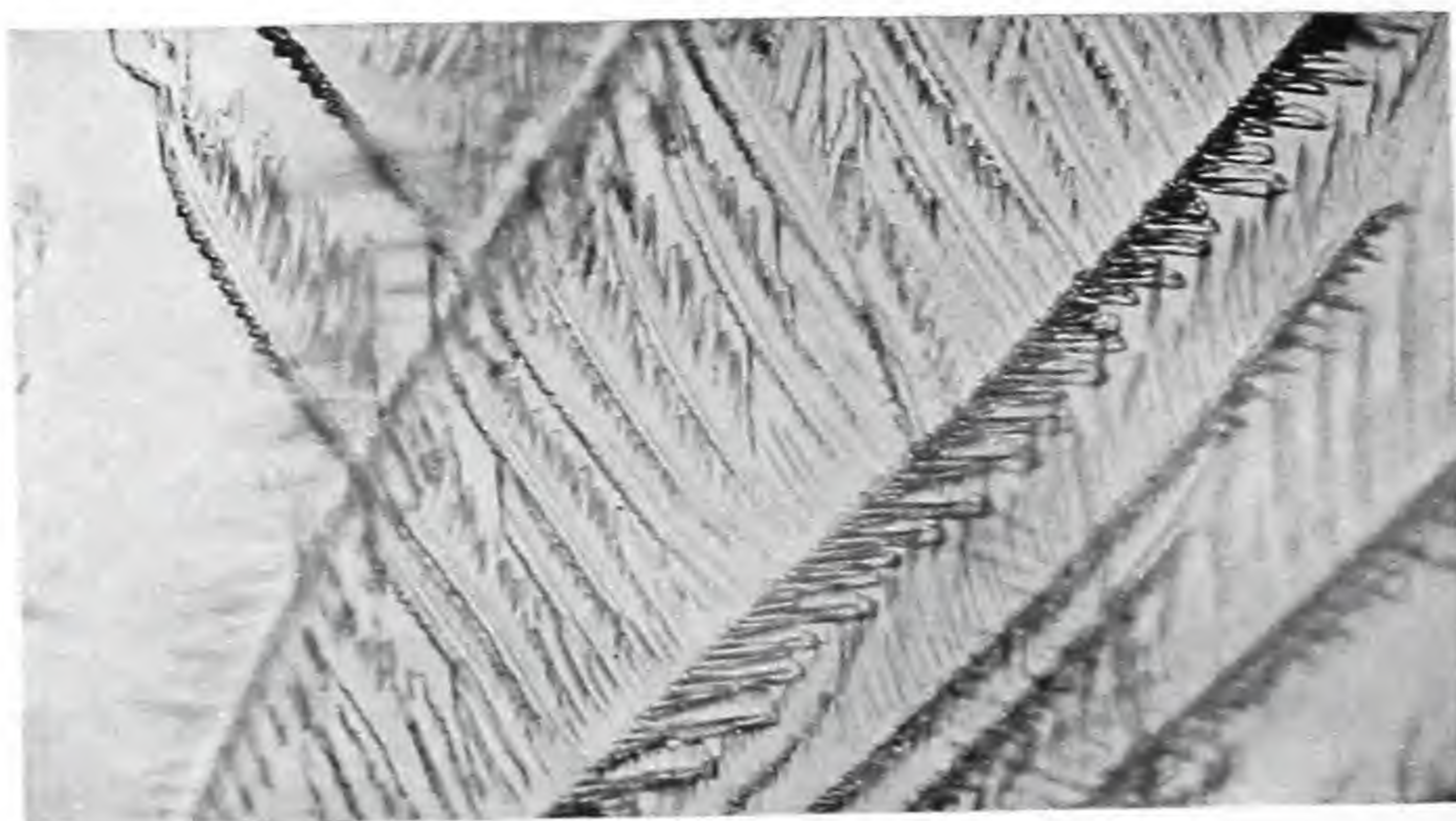


Fig. 219. Cocaine with chloroplatinic acid.

### CHLORAUIC ACID

Follow the directions as given for chloroplatinic acid except that the reagent used is chlorauric acid. Compare the results with those in Fig. 220.

## 9. CANNABIS INDICA (MARIJUANA)

The common hemp plant (*Cannabis sativa* L.) that grows in warm climates contains a resinous substance, particularly in the leaves and flowering tops, which is physiologically potent. This plant varies in height from 4 to 16 ft. It grows wild in many parts of the United States (*Cannabis americana*) and is indigenous to or cultivated in other countries such as India (*Cannabis indica*), Iran, Greece, Egypt, Brazil, etc. Numerous vernacularisms have been employed to designate cannabis or mixtures containing the resin or active principle of cannabis:

- American — marijuana, weed, tea
- Asiatic — hashish, charas, bhang, ganja
- African — dagga, kif

In America cannabis is usually smoked in the form of a home-made cigarette which is called a *reefer*, *muggle*, or *stick*. However, it may be mixed with foods (usually sweetmeats) and eaten, or it may be steeped like tea and drunk. Cannabis is said to be habit forming if it is used repeatedly over a period of time. The physiological effects of cannabis vary with the number of cigarettes



smoked, the species, and the potency of the cannabis used. Individuals may be affected differently. Some experience a feeling of euphoria and excitement, others melancholia and depression. Thinking becomes abnormal; colorful hallucinations, frequently erotic, are experienced; behavior is impetuous, haphazard; notions are impulsively carried out.

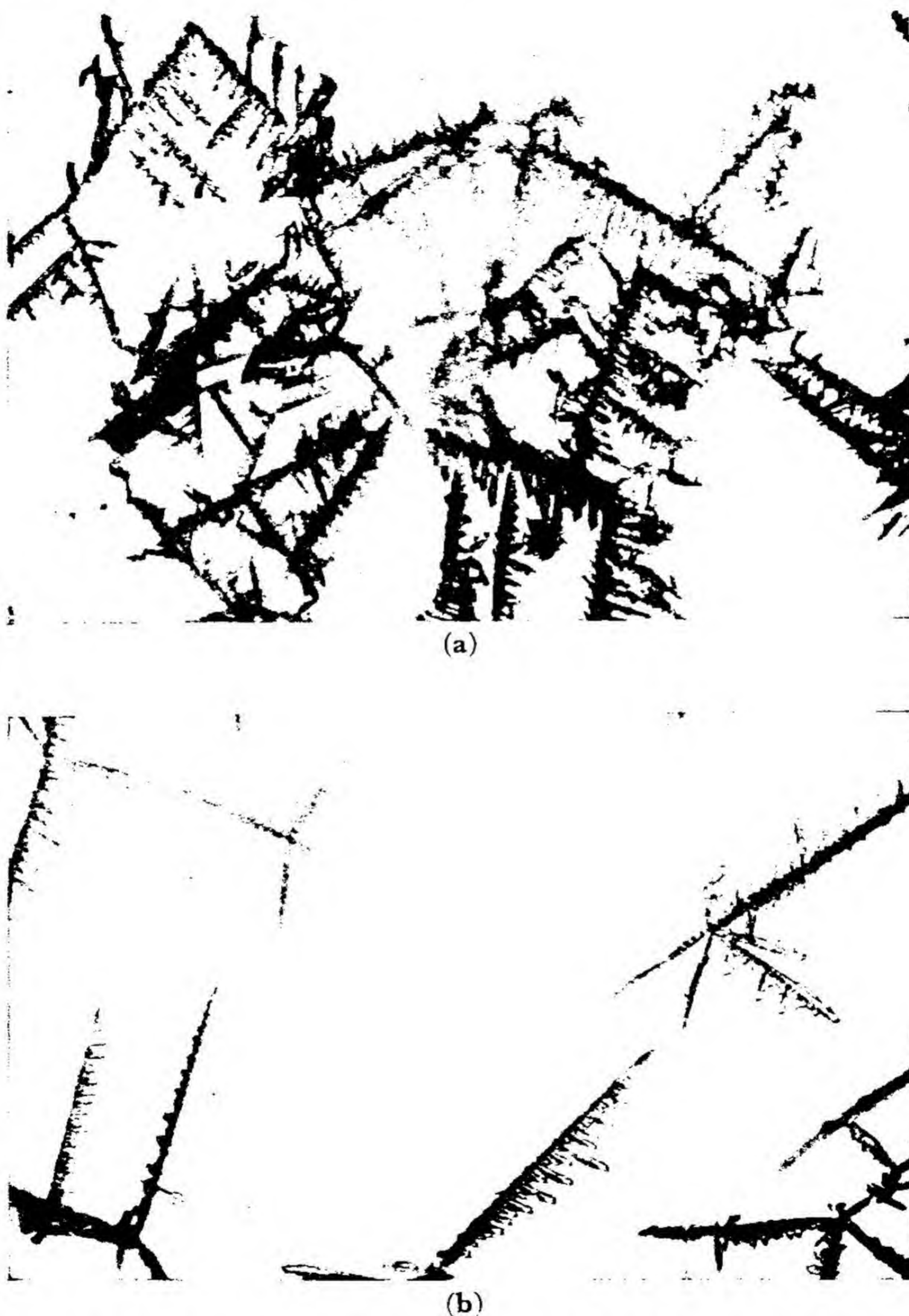


Fig. 220. Cocaine with chlorauric acid: (a) 1:1000; (b) 1:500.

### Chemical Tests

#### *DUQUÉNOIS TEST*

A portion of the material suspected of containing cannabis is placed in a test tube. One or two milliliters of the Duquénnois reagent are added and the



mixture is shaken for about one minute. One milliliter of concentrated hydrochloric acid is then added to the test tube. If cannabis is present a series of color changes will be observed: the solution turns pink, rapidly changing to violet, which on standing finally turns deep blue. With a fresh sample of cannabis, the pink color frequently is not observed, as the blue color develops immediately upon addition of the reagent.

### *BEAM TEST*

Place a portion of the suspected cannabis in a test tube and add 10 ml of light petroleum ether. Shake the tube for one minute and decant the liquid into a glass evaporating dish. Repeat this process using another 10 ml of petroleum ether. Permit the petroleum ether to evaporate at room temperature in a hood. Remove a portion of the resin on the bottom of the evaporating dish with a glass rod and spread it out on a piece of filter paper. Add 4 or 5 drops of an alcoholic potassium hydroxide solution (10 g per 100 ml absolute alcohol) to the resin on the filter paper. After the alcohol has evaporated, add 4 or 5 more drops of the reagent to the resin. Repeat this procedure 4 or 5 times. If the resin is that of cannabis, a violet color develops slowly and unevenly at the periphery of the ring formed by the spread of the alcohol. The violet color is not very intense and in some cases may be quite faint. Indeed, for certain species of cannabis the Beam test may not be positive at all.

### *BOUQUET TEST*

A portion of the material suspected of containing the cannabis is powdered and placed in a test tube. About 5 ml of ethyl acetate are poured into the tube; the contents are shaken for one minute and then filtered. An additional 5 ml of ethyl acetate are used and the procedure repeated. The combined extract which is generally colored green as a result of chlorophyll is decolorized with the minimum amount of decolorizing charcoal possible. After removing the charcoal by filtration, the test tube containing the clear ethyl acetate is placed in a beaker of boiling water. When the solvent has been removed by evaporation, the residue is dissolved with 1 ml of acetone. About 0.5 ml of freshly prepared Bouquet reagent (2 parts concentrated sulfuric acid and 3 parts absolute ethyl alcohol) \* is then added to the tube. On standing, a brownish-red color develops slowly if cannabis is present. If a few drops of water are then added to the solution a whitish opalescence is noted. While certain other materials also develop a brown color with this reagent, they do not react similarly when water is added.

### **Microscopic Examination**

#### *EFFERVESCENCE TEST*

When dilute hydrochloric acid is added to powdered cannabis an effervescence of gas results which is visible under the microscope at 100X. Care must be exercised to add the acid carefully in order to prevent damage to the objective of the microscope.

\* Prepared by adding the acid slowly to the alcohol with stirring.



### BOTANICAL FEATURES

The botanical features of cannabis are quite characteristic and are easily recognized. Figure 221 is a photograph of a leaf of the cannabis plant. The following features of ground cannabis are quite readily observed by means of a microscopic examination (ca. 100X):

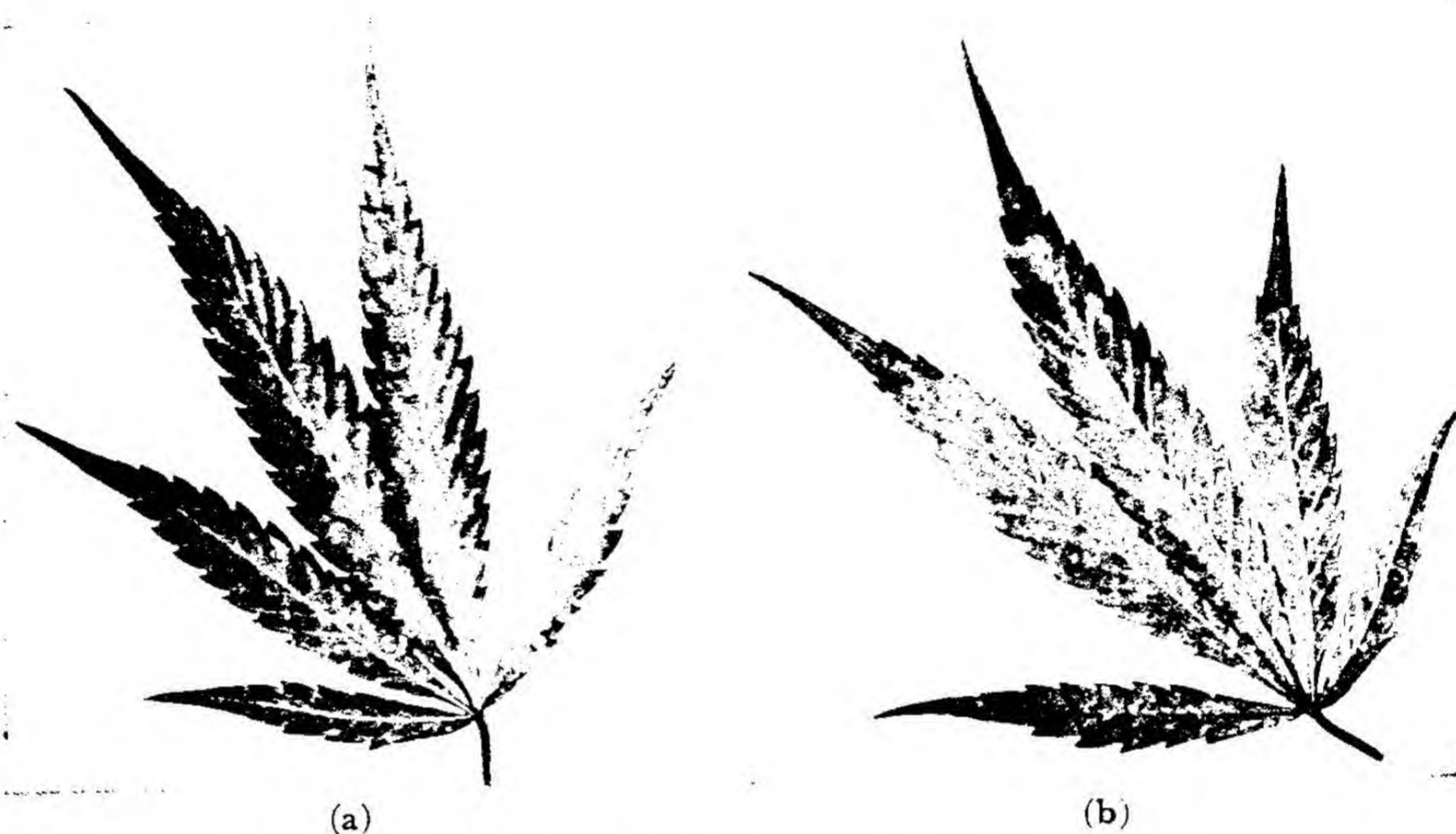


Fig. 221. A marijuana leaf: (a) upper side; (b) lower side.

Color: green, greenish-brown, or brown.

Epidermis of leaf: lower surface has many stomata and sinuate walls. Upper surface has no stomata and walls are straight.

Hairs: There are both glandular and nonglandular hairs. The nonglandular hairs are quite numerous and have a pointed, slender apex with an enlarged base that usually contains a crystalline mass or cystolith. Nonglandular hairs are rigid, curved, and unicellular. There are two types of glandular hairs; one is short with a unicellular stalk, the other long with a multicellular, tongue-shaped stalk and a head or gland which is globular in shape and has from 8 to 16 cells.

### EXERCISES

Using known narcotics, perform all the tests described above. Prepare a list of those reagents which give the same results with different narcotics.

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# PART G

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## DOCUMENT EXAMINATIONS







# CHAPTER 34

## INKS

### 1. INTRODUCTION

In the examination of questioned documents it is sometimes necessary to investigate many questions concerning the ink used in writings on the document. For example, if it is alleged that alterations have been made, it is advisable to compare the type of ink used in the undisputed original writing with that of the alleged alteration; if chemical examination shows that two different types of ink were used, the inference to be drawn is quite obvious. Another point of interest lies in the question of the age of inks: is the writing as old as the date it bears; were the writings of chronological business entries all made at the same time or over a period of time as would be natural in the course of business? Finally, it is sometimes of great interest to learn whether or not a particular bottle of ink was used for the writings on two different documents.

In the following paragraphs the types of ink in general business use today and those which were used in the past will be discussed with regard to their chemical composition, so that an adequate basis will be provided for the understanding of the chemistry of the methods used to distinguish among inks. In addition, the difficulties that exist in attempting to obtain positive information in other investigations concerning ink will be better appreciated.

The problem of introducing chemicals into a person's ink supply for the purpose of marking it for future identification is treated elsewhere in the text and the reader who is interested should consult Chapter 28.

Since it is necessary to employ chemical as well as physical methods in the following procedures, it is advisable that the person conducting the examinations be trained in analytical chemistry. At least those methods that require a knowledge of chemistry should be used only by a chemist. This admonition is in keeping with the spirit of the advice offered by Mitchell<sup>1</sup> and Lucas concerning the role of the chemist in document examinations.

### TYPES OF INK

#### 2. IRON GALLOTANNATE INK

This type of ink has been and is today the most frequently used for entries in record books and for business purposes in general. Iron gallotannate or nut-



gall inks are solutions and not merely suspensions of solid coloring matter in a liquid medium. Thus the ink is able to penetrate into the interstices of the fibers, thereby inscribing the writing in the body of the paper and not merely on the surface, so that its removal is more difficult to accomplish. It will be seen later, in our study of restoration of erasures, that this ability to pass into the body proper of the paper makes it more difficult to eradicate the original writing.

### Composition

The general constituents of black and blue-black, nutgall inks follow, together with the reasons for adding each. A fuller explanation of the function of the more important constituents will be set forth in a series of equilibrium equations. These reactions will further serve to explain, in terms of displacement of the equilibria, the action of the chemicals generally recommended for testing ink.

Constituents	Function
Ferrous sulfate	{ See equilibrium equations in sec. 3 below
Tannic acid*	
Gallic acid†	

### Provisional Coloring Matter

A dye material such as Soluble Blue (C.I. 707) is added to render the writing immediately legible. Today this is the general practice, but in the distant past no such provisional coloring matter was added.

### Preservative

A compound such as phenol or boric acid is added to prevent mold and bacterial growth. The amount of preservative used is quite small, usually less than 1 per cent. Other constituents which likewise are used in limited amounts include humectants, such as glycerin, and surface-active agents.<sup>2</sup>

### Protective Colloid

Formerly gum arabic and dextrin were added to prevent precipitation of any ferric tannate which formed on standing. In general, the use of protective colloids has been discontinued.

### Inorganic Acid

Inorganic acids such as hydrochloric or sulfuric are added to prevent formation of ferric tannate (and ferric gallate, etc.). In terms of equation 2 below, this may be regarded as a repression of the ionization of the tannic acid by the mineral acid, so that the concentration of tannate ion is below that necessary to exceed the solubility product of ferric tannate.

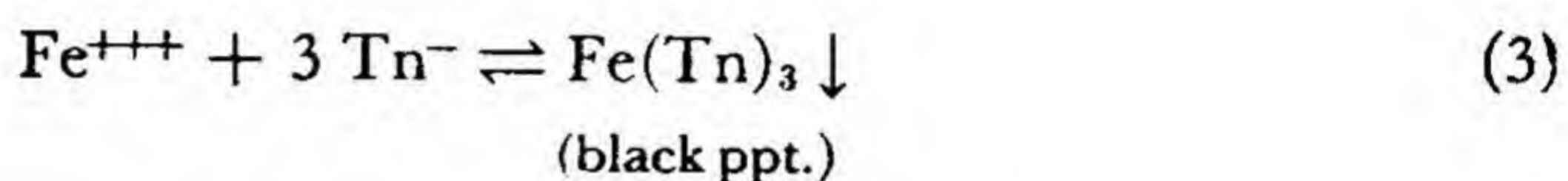
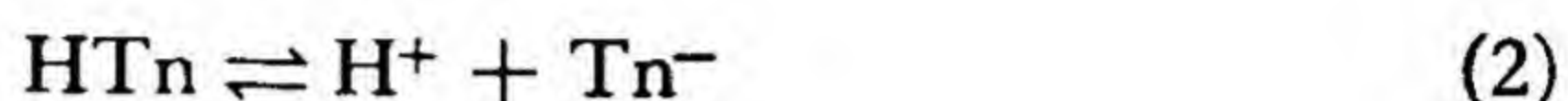
\* Tannic acids are widely distributed in nature, being found in plants, leaves, and trees. The chief source, however, is gall nuts and the bark of the oak, sumac, hemlock, and other trees. Galls or gall nuts are excrescences or warty growths on the leaves of various trees, formed as a result of the puncture of the leaves or bark by certain insects.

† Gallic acid is also obtained from natural vegetable sources.



### 3. THE CHEMISTRY OF IRON GALLOTANNATE INKS

The following equations in addition to indicating the chemical changes in writing ink after drying will further illuminate the usual, but not entirely satisfactory, explanation offered by Mitchell<sup>3</sup> as an interpretation of the chemistry involved in the examination of writing made with nutgall ink. For the purposes of simplification, only tannic acid will be considered. For convenience the tannate radical will be indicated by the symbol  $Tn^-$ .



After the ink is applied to the paper the air oxidizes the ferrous ion to ferric ion (equation 1); this combines with the tannate ion (equation 2) to form an insoluble black precipitate (equation 3).

Mitchell<sup>4</sup> claims that complex iron tannate compounds are formed. Equation (3) is therefore only a part of the complete story; however, for didactic purposes and from a pragmatic point of view these equilibria equations may be considered satisfactory.

The time required for these reactions to be completed after the ink is placed on the paper depends, as always, upon the conditions under which they are permitted to take place. For example: the amount of air, moisture, heat, and light to which the paper was exposed, as well as the nature of the sizing, degree of acidity of the paper, and use of or failure to use a blotter, are some of the variables which influence the length of time required for the reactions to go to completion. In terms of outward appearance to the naked eye, the time required for a black color to begin to appear may be as short as a week in the summer, while in the winter it may take several months. However, a few years or more may be required for the ink to turn completely black and to develop its greatest intensity.

In the tests used to distinguish among the various kinds of black inks it is convenient to classify the generally recommended reagents according to their chemical action on nutgall ink. Thus several reagents will be grouped into each class; the interpretation of their chemical action in terms of the reversal of equation (3) and the establishment of new equilibria applies to all reagents in the same group.

#### Inorganic Acids

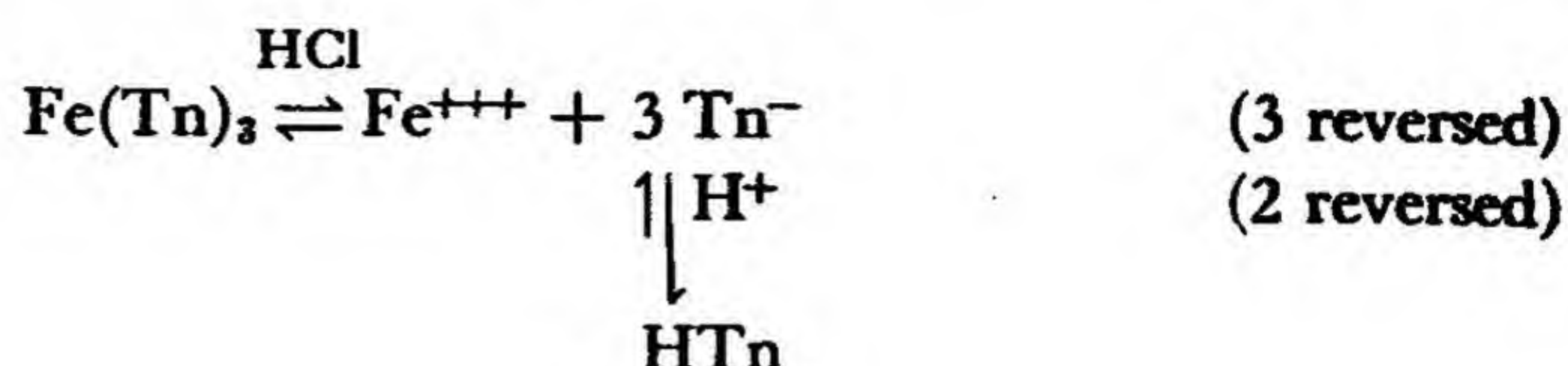
Hydrochloric acid

Sulfuric acid

Nitric acid

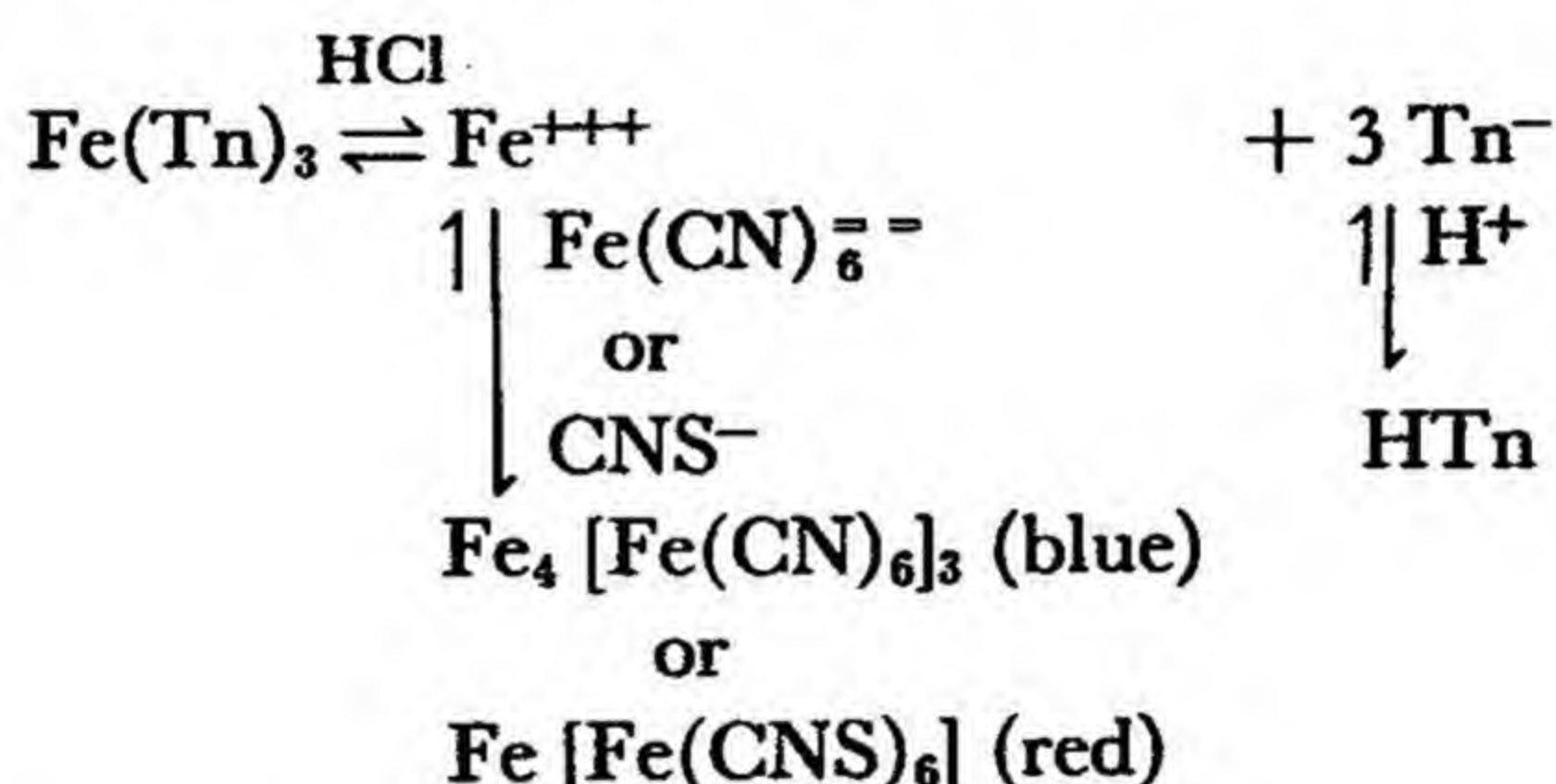


The action of these acids on ferric tannate may be illustrated by hydrochloric acid.



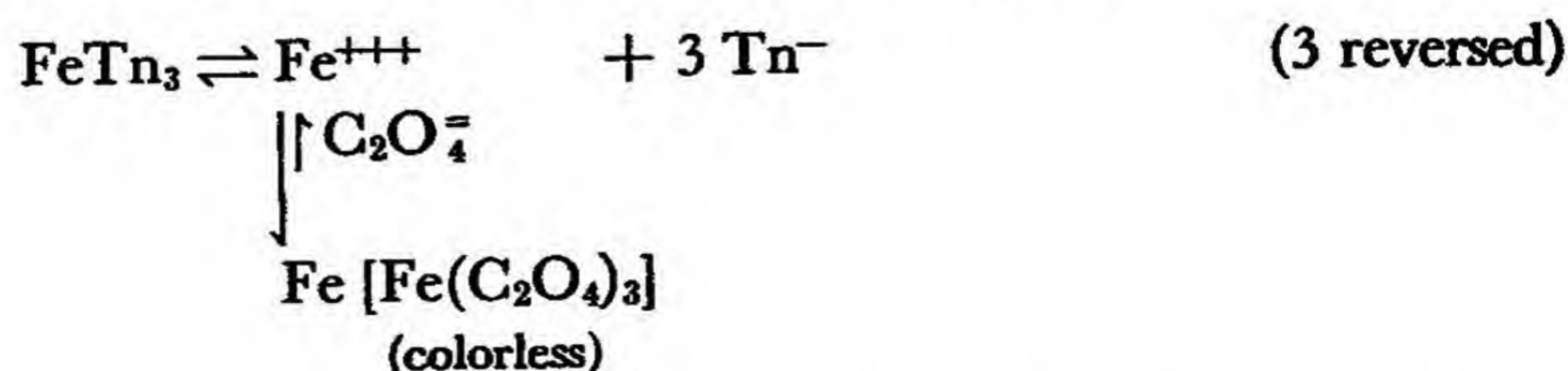
The ferric ion (ferric chloride) accounts for the faint yellow coloration sometimes observed after addition of an inorganic acid. Of course this happens only if the ink is so old that the provisional coloring matter has been destroyed by oxidation, or if it was never present in the ink under examination. In most cases, however, addition of inorganic acids will result in a change of color from black or blue-black to light blue. This latter color is the result of the provisional coloring matter which usually is added to inks of this type.

It is perhaps most appropriate to discuss potassium ferrocyanide and potassium thiocyanate at this point since it is necessary to use an acid solution of these reagents to conduct the tests. The reaction is the same as for inorganic acids alone except that the ferric ion is also "tied up" by these reagents, thereby forcing the equilibrium even more to the right, viz.:



### Complex Ion Formation

Oxalic acid, tartaric acid, and citric acid are organic compounds that form soluble complex salts with various heavy metals including iron. Perhaps the best known example of this type of complex salt formation is that of copper with tartaric acid in Fehling's solution. The following equation illustrates how these acids "tie up" ferric ions and hence are of value as ink-testing reagents.

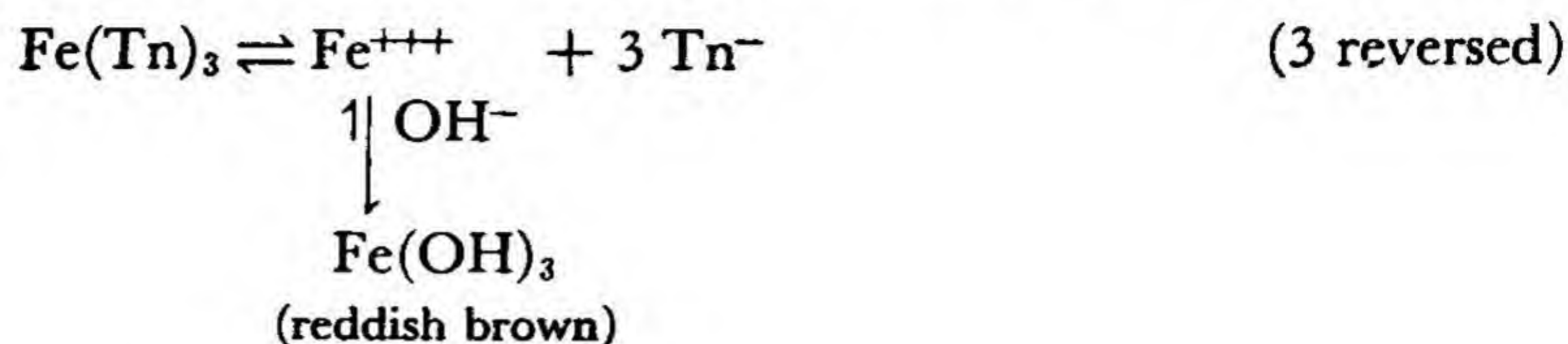


Since these reagents have no effect on the provisional dye, the usual result following their application is the development of a light blue color unless the ink is very old or never had coloring matter added. In these latter cases the reagent will cause the writing to fade or disappear.



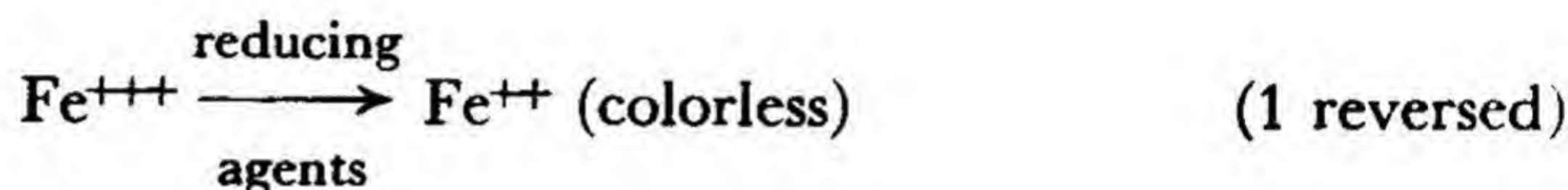
### Bases

Sodium hydroxide and potassium hydroxide, as well as sodium thiosulphate in ammonia solution, react with iron gall inks to form a red or reddish-brown color that results from the formation of ferric hydroxide as shown below:



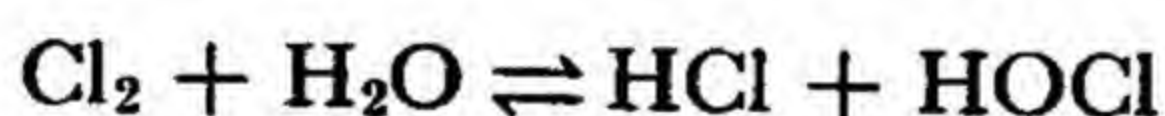
### Reducing Agents

Stannous chloride, titanous chloride, sulfurous acid, and hydrogen (zinc and dilute hydrochloric acid) are reducing agents that reduce the ferric ion to the colorless ferrous ion, and in some cases may destroy the provisional coloring matter.



### Oxidizing Agents

Bleaching solutions (sodium hypochlorite or calcium hypochlorite\*) and bromine or chlorine water are agents that function in two ways: (a) they destroy the provisional coloring matter by oxidation; (b) they act on the iron tannate in the same fashion as inorganic acids. Since chlorine dissolves in water to form hydrochloric and hypochlorous acid this similarity of action on iron tannate is to be expected. Bleaching solutions are most effective below *pH* 7 in destroying the color of the ink.



## 4. LOGWOOD INK

From the wood of the logwood tree a natural coloring material (haematoxylin) is obtained by extraction with water. This extract was first used in iron tannate inks about 1763 as an additional ingredient to make the writing more intense<sup>5</sup> and, perhaps, more permanent. In 1847 Runge used logwood extract and potassium chromate as the principal constituents of a new type of ink.<sup>6</sup> Later in 1857, alum, copper sulfate, and logwood extract were used; in 1859 alum and logwood were employed; and in 1875 copper sulfate and logwood extract were mixed to form another variation of logwood ink. The use of a ferrous compound as an ingredient disappeared in these later logwood inks. In 1882 potassium dichromate was used as the principal ingredient to be added to logwood extract. Hydrochloric acid and phenol were also added — the former to prevent the formation of a precipitate and the latter to act as a preservative.<sup>7</sup> In certain formulas, sulfuric acid is used in place of hydrochloric acid.

\* A solution of chloride of lime may be used also.



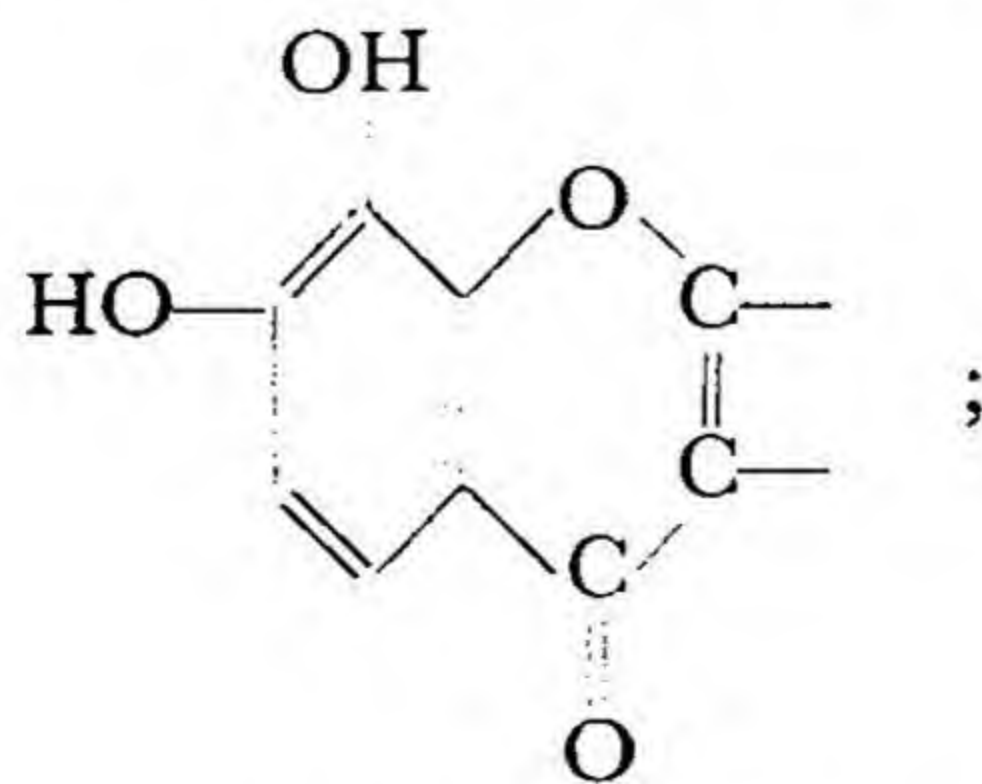
The color of logwood inks depends upon the inorganic salt added; but on drying and standing, they turn black; with chromium salts they yield the deepest black. At the present time logwood inks are practically obsolete, although they are reported to be still in use in Germany.<sup>8</sup>

While it would be interesting to attempt an interpretation of the chemistry of the reactions of this type of ink, it is beyond the scope of this book because of their involved nature and the complicated, even uncertain, chemistry involved. However, for those who wish to speculate on possible interpretations of the color changes which occur when the test reagents are added to the writing, a brief statement concerning the production of color in organic compounds should be helpful.<sup>9,10</sup>

## 5. COLOR AND CONSTITUTION

The first attempted explanation of color in organic compounds was based on the presence of certain unsaturated groups, called *chromophores* or *color producers*, in the molecule. Other groups which deepen the color were called *auxochromes* or *color intensifiers*. Later it was recognized that salt formation also contributed to the production of color in organic compounds. Stieglitz<sup>11</sup> unified these ideas into a theory based on the oscillation of electrons owing to an intramolecular oxidation-reduction process in which the chromophoric groups were regarded as the oxidizing agents and the auxochromic groups acted as reducing agents. This concept has been broadened so that at present color production is ascribed to resonance (a theory developed in quantum mechanics). Briefly, resonance may be described as a condition of a molecule that permits several electronic structures of approximately the same energy content to be assigned to it. Resonance involves only electron shifts, and is not concerned with any shifts of the atoms themselves within the molecule. Thus organic dye molecules exist in resonating forms because they possess electron acceptors (chromophores) and electron donors (auxochromes) and an unsaturated (conjugated) system that serves as an intermediate path over which the electronic resonance may be transmitted.

Haematoxylin, the natural coloring principle obtained from logwood, is converted into haematein by oxidation when allowed to stand in air. This latter compound contains a substituted flavone nucleus,



thus the essential requirements for the production of color in organic compounds are satisfied. The unsaturated ring groups (quinoid structure) may be regarded



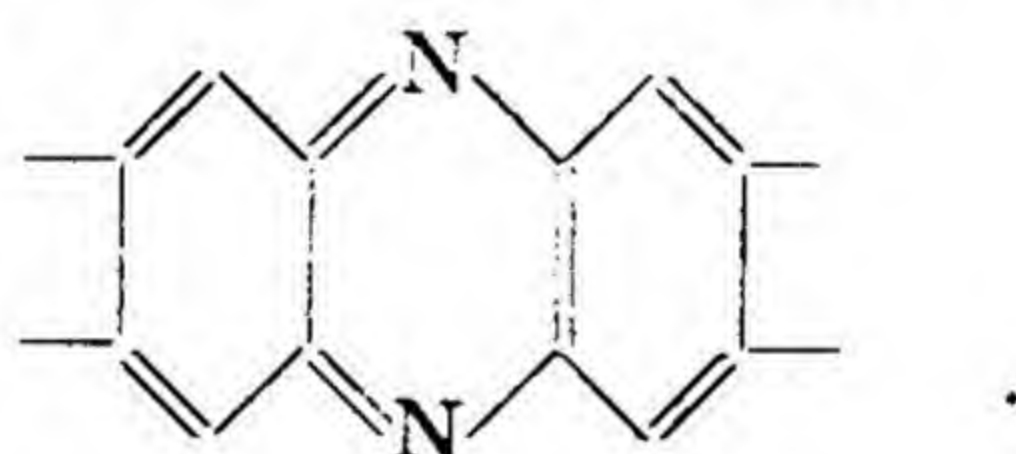
as the chromophore, and the hydroxyls as the auxochrome, while salt formation may occur in acid medium at the heterocyclic oxygen and in basic medium at the phenolic groups. In addition the compound is capable of inter- and intramolecular oxidation and reduction as well as being able to resonate between several alternative electronic structures so that it would indeed be difficult to predict the resultant color after the addition of a reagent.

## 6. NIGROSINE INK

In 1867 a water solution of a synthetic black compound prepared from aniline and nitrobenzene was introduced as a blue-black or purple-black ink for stylographic pens. This type of synthetic ink is usually referred to as *Nigrosine Ink* but it has also been called *Indulin Ink* and *Black Aniline Ink*.<sup>12</sup>

No new compound is formed by oxidation after this ink is applied to the paper, so that the lines are merely deposited organic solids that were in solution in the ink before it dried. Therefore it should be expected that water would affect writings made with this ink by redissolving the nigrosine. Thus writings made with this ink are easily smudged, affected by moisture, and may be washed off the paper with little difficulty, regardless of the length of time they have been on the document. This ink, therefore, does not possess the permanence of iron gallotannate or logwood inks; but, on the other hand, it resists the action of chemical reagents, including many of the usual ink testing reagents.

The constitution of nigrosine is unknown. A similar or related dyestuff, however, is induline, which contains an azine ring:



Inasmuch as the structure of nigrosine is unknown, it is impossible to write equations which will serve to interpret the chemistry of the color changes which take place upon the addition of certain reagents. However, the general requirements, including resonance possibilities, for color production must be present in the molecule; again, the difficulties of interpretation of color changes resulting from the reagents which are used in testing will be great even after the structure is finally elucidated.

## 7. CHINESE, INDIA, AND CARBON WRITING INKS

Historically the use of carbon as an ink material dates back to more than 3000 B.C.; hence it is the oldest writing substance known. It has been known under various names such as *Chinese Ink* and *India Ink*. Today, finely divided carbon is held in colloidal suspension and used to produce deep black drawing and writing ink.<sup>13</sup>

As carbon is chemically inert to the usual ink testing reagents, it will resist all attempts at oxidation or reduction, and remain uninfluenced by changes in



acidity. However, this type of ink does not penetrate deeply into the fibers of the paper (particularly if well sized), so that it may be easily washed off. In testing, therefore, the document examiner must be aware of this fact and should avoid mistaking this washing or mechanical removal of the carbon by the solvent of the reagent for a chemical reaction such as bleaching.

### 8. COLORED WRITING INKS

Although colored writing inks are much more popular today than formerly, they are, nevertheless, infrequently used in writings on important documents. For this reason an extended treatment of this subject will not be attempted here. For those interested in this subject, the treatments by Mitchell,<sup>14</sup> Lucas,<sup>15</sup> Woodman,<sup>16</sup> and Rhodes<sup>17</sup> should prove adequate for most purposes.

Formerly colored inks were manufactured from coloring materials found in nature, such as indigo. Today, however, almost all colored inks are composed of synthetic aniline dyestuffs dissolved in water.

In certain colored inks of modern manufacture ammonium vanadate is added to render the writing more permanent. Hence it is advisable to make an examination for vanadium, if a comparison between two similarly colored inks is being conducted (see Chap. 37). Obviously, finding vanadium in one sample of writing and absent in the other would exclude the possibility of both writings having been made with the same type of ink.

### 9. PHYSICAL METHODS USED IN THE EXAMINATION AND COMPARISON OF INK WRITING

The document must first be photographed (1:1 scale) to record its appearance at the time at which it was submitted for examination.

The whole document and especially those parts in question should be examined with the naked eye, using reflected and transmitted light as well as ultraviolet light, although no great value is attached to the latter examination. A hand magnifier and a binocular microscope should also be used, noting any alterations, erasures, destruction of sizing, etc. A color comparison microscope may reveal valuable information regarding the color of different ink lines.<sup>18</sup>

Next, a series of colored filters should be employed to view the document; any differences detected should be photographed, using an appropriate film. An infra-red photograph should be made also in order to obtain, if possible, some differentiation between the ink writings or to detect other differences that may exist in the subject matter under examination.<sup>19</sup> Nigrosine ink may sometimes be distinguished from other inks under a low-power microscope (20X) by the outer portions or edges of the ink line which are markedly darker than the inner portion of the stroke.

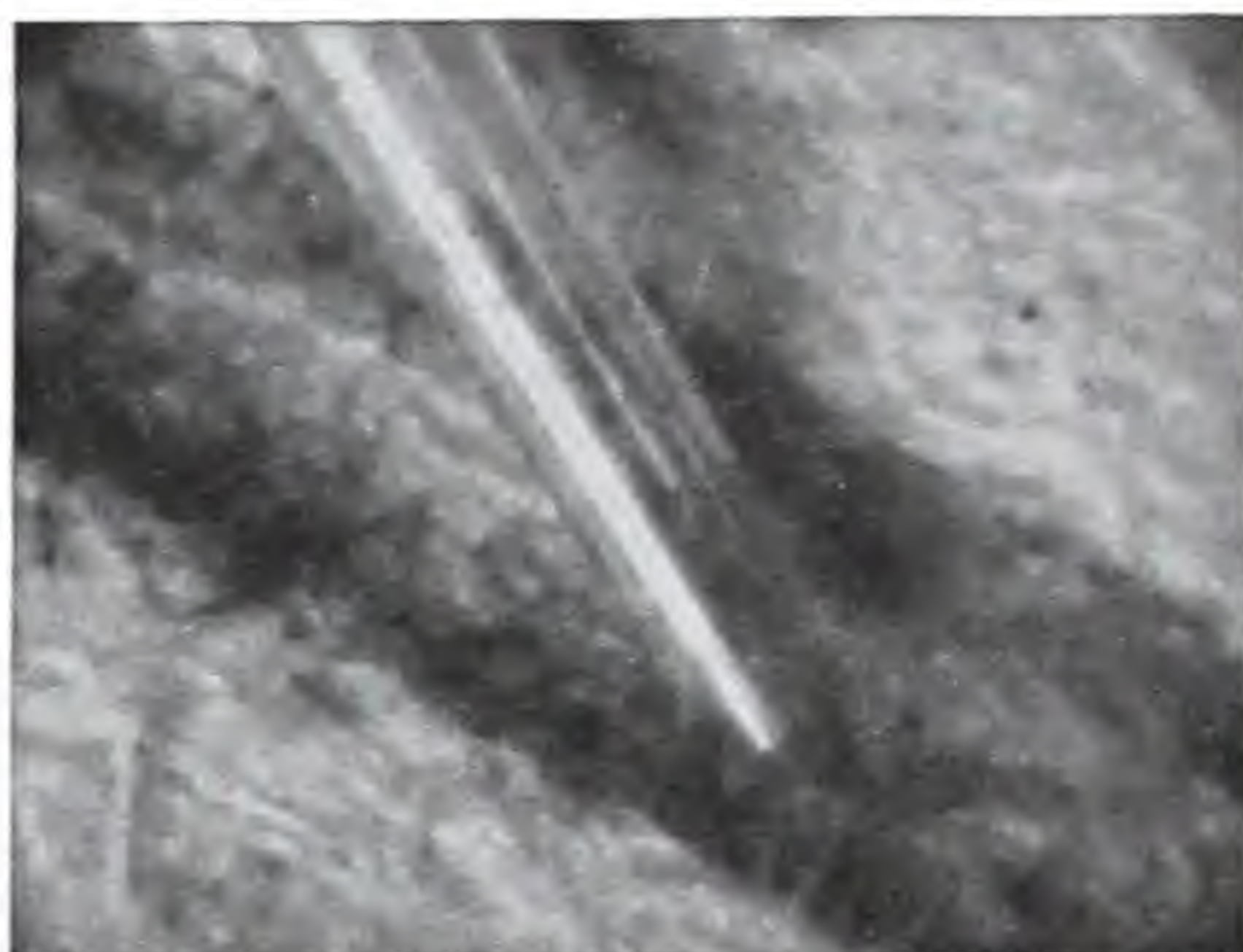
### 10. CHEMICAL METHODS USED IN THE EXAMINATION AND COMPARISON OF INK WRITING

In Table 23 most of the reagents recommended for testing inks are listed; the concentration of each reagent is specified. An asterisk next to a reagent



indicates that it is the most generally useful and should be used before others of the same type.

The reagents when not in use should be kept in small, tightly closed bottles. A brown colored bottle holding 50 ml of reagent, with a dropper passing through the stopper, is satisfactory. Reagents are applied to the ink line by means of a very fine capillary pipette, with the assistance of a hand magnifier or low-power microscope (Fig. 222). The pipette may be prepared by heating ordinary glass tubing and drawing it out until a sufficiently fine capillary is produced. Sharpened wooden toothpicks may also be used to apply the reagent. The writing is examined after a few minutes by reflected and transmitted light. If no color change has taken place it is examined in one-half hour and again in 12 hours if necessary. When the reaction is completed in a few minutes, the excess reagent should be removed with blotting paper. Several applications of water may also be used carefully to dilute and remove the last traces of the reagent, thereby providing additional protection from any destructive chemical action on the



**Fig. 222. Applying the test reagent to an ink line by means of a capillary pipette (40X).**

paper. The area so tested must not be prominent; indeed, if done carefully, it may require a hand magnifier or low-power microscope to reveal any details concerning the places at which the tests were conducted. Obviously, if these tests are carried out in such a delicate fashion that magnification is required to reveal the place, it is necessary to keep a record of the positions at which they were conducted. Of course, the place selected for the test should be an unimportant portion of the pen stroke. If it is necessary, however, to test an important section of the document and if the entire alteration is slight, it would be advisable to obtain permission from competent authority before proceeding with the work. In extreme cases, where the disputed section may be changed or damaged so that the evidential value of the document is impaired, it would be advisable not to perform the tests until ordered by a court and then only after an explanation has been given of the possible consequences with respect to the changes that may result at the significant portion of the document.

An examination of Table 23 shows that relatively few reagents are required to test inks. Hydrochloric acid distinguishes iron nutgall ink (the color disappears or turns light blue) from logwood ink (a red color develops); a negative reaction indicates that either a nigrosine or carbon ink is under examination. These latter inks can be distinguished by sodium hypochlorite which turns nigrosine ink brown and does not affect carbon ink. The reagents in Table 23 include those suggested in the literature as being useful. When they are studied



TABLE 23

REAGENTS	IRON GALLOTTANATE INKS		LOGWOOD INKS		NIGROSINE INKS	CARBON BLACK INKS
	With Blue Provisional Coloring Matter	With No Provisional Coloring Matter	With Potassium Chromate	With Copper Sulfate		
ACIDS						
*Hydrochloric 5%	Blue	Disappears, leaving slight yellow coloration	Red	Red	May be smudged, otherwise no effect	No effect, may be smudged or removed by blotter
Sulfuric 5%	Blue	Disappears	Red	Red	May be smudged, otherwise no effect	No effect, may be smudged or removed by blotter
Nitric 5%	Blue	Disappears	Red	Red	May be smudged, otherwise no effect	No effect, may be smudged or removed by blotter
Oxalic 10%	Blue	Disappears	Violet-red	Orange-yellow	May be smudged, otherwise no effect	No effect, may be smudged or removed by blotter
Tartaric 10%	Blue	Disappears	Light brown	Light brown	Runs, dark blue at edges	No effect, may be smudged or removed by blotter
Citric 10%	Blue	Disappears	Violet-red	Orange-yellow	Runs, dark blue at edges	No effect, may be smudged or removed by blotter
BASES						
*Sodium hydroxide 2%	Reddish brown	Reddish brown	Brown	Runs, dark red at edges	Runs, dark violet at edges	No effect, may be smudged or removed by blotter
REDUCING AGENTS						
*Stannous chloride 10% in 0.1 N HCl	Blue <sup>a</sup>	Disappears	Red	Red	May be smudged, otherwise no effect	No effect, may be smudged or removed by blotter



Titanous chloride 5%	Blue†	Disappears	—	—	May be smudged, otherwise no effect	No effect, may be smudged or removed by blotter
Saturated solution of SO <sub>2</sub> (sulfurous acid)	Blue†	Disappears	Ashen violet	Red	May be smudged, otherwise no effect	No effect, may be smudged or removed by blotter
OXIDIZING AGENTS						
*Sodium hypochlorite 10% (acidified)	Disappears	Disappears	Disappears	Disappears	Brown	No effect, may be smudged or removed by blotter
Chloride of lime (saturated solution)	Disappears	Disappears	Disappears	Disappears	Brown	No effect, may be smudged or removed by blotter
Chlorine water (saturated solution)	Disappears	Disappears	Disappears	Disappears	Brown	No effect, may be smudged or removed by blotter
Bromine water (saturated solution)	Disappears	Disappears	Disappears	Disappears	Brown	No effect, may be smudged or removed by blotter
MISCELLANEOUS						
Potassium ferrocyanide 5% in 0.1 N HCl	Blue	Blue	Red	Red	May be smudged, otherwise no effect	No effect, may be smudged or removed by blotter
Potassium Thiocyanate 5% in 0.1 N HCl	Red	Red	—	—	May be smudged, otherwise no effect	No effect, may be smudged or removed by blotter
Sodium thiosulfate 5% in 5% NH <sub>4</sub> OH	Reddish brown	Reddish brown	—	Dark blue	Dark violet, smudges easily	No effect, may be smudged or removed by blotter

\* Indicates the most generally useful reagent of the group.

† In some cases, the provisional dye may be decolorized.



from a chemical standpoint the purpose each serves is understood and many duplications, some unwise, are seen; for example, it would be obvious to a chemist that sulfuric acid should not be used unless precautions are taken for its neutralization, otherwise the paper will be harmed in time by the destructive action of the sulfuric acid. Since it is possible for a poor iron gallotannate ink to be partially removed by the solvent action of a reagent solution, it is advisable to test the blotting paper (used in removing the reagent) with potassium ferrocyanide or thiocyanate. In this way one may ascertain if an ink easily removed by water is nigrosine or carbon ink, or if it is a poor iron gallotannate ink.

## 11. AGE OF INKS

One of the most important aspects of ink problems in forensic chemistry is that of the age of a questioned writing. Other inquiries on this subject can be related to the question: "Were the writings all made at the same time or were they done at different times?" The problem raised in the first half of the question occurs when it is necessary to decide whether an alleged alteration or addition to a document was made at the same time as the original or was introduced at a later date. It will be assumed for the situation described that the entire document, including the questioned portions, was written with the same type of ink. A case in which information concerning the last half of the question would prove helpful occurs when it is necessary to render a decision about entries in business records, supposedly made in chronological order over a period of time during the regular course of business, but suspected of having been written all at the same time. In connection with this situation, knowledge of the type of ink or inks employed would be of no assistance, for one type may or may not be used throughout and it is not beyond the resources of a skilful operator to simulate the more usual and genuine appearance where many pens and inks are used in the writing.

In certain cases of more or less infrequent occurrence it has been claimed that specific, positive solutions to this problem were and are possible.<sup>20, 21, 22, 23</sup> Unfortunately, however, no general, objective solution is possible for most cases in which the age of ink writing is important. Therefore, no specific directions will be given for the selection of a procedure to use in a particular case. It is the aim in the sections below to survey comprehensively the various procedures that have been described in the literature as methods for determining the age of writing and to indicate their limitations. Although it undoubtedly would be more desirable to have solutions prescribed for all cases, it will be appreciated after a reading of the text that this is impossible. An understanding of the various methods will enable the document examiner to select the most suitable for a particular case and will provide a background for any further experimentation that may be necessary for those few cases in which the conditions appear that it might be possible to obtain information concerning the age of the writing in question.

The methods employed depend upon (a) physical phenomena such as match-



ing the color of the ink writing with standard colors or with itself over a period of time and (b) chemical reactions, certain aspects of which are alleged to reveal information concerning the length of time the ink has been on the paper. Inasmuch as many of these methods depend upon more or less rapid oxidation of the ink, it should be apparent that they are not applicable to nigrosine and carbon inks since they are not subsequently oxidized after being placed on paper. The following is a résumé of the various methods proposed in the literature for obtaining data on the age of questioned ink writing.

## 12. PHYSICAL METHODS FOR ESTIMATING THE AGE OF WRITING

Since it is usual to add provisional coloring matter to iron nutgall inks pending the formation of the black iron tannate, it is obvious that many changes in color will occur in this process. For example, Mitchell<sup>24</sup> states that the color is bright blue first, but turns violet as the other pigment, i.e., the iron tannate, is formed. The completion of the change, i.e., the development of maximum intensity, varies greatly with the conditions. If a pen is used to apply the ink and if the writing is then kept in a closed book the greatest intensity may not be attained for upwards of a year.

Osborn<sup>25</sup> similarly points out that the initial stages of the darkening of iron nutgall inks are much more rapid than the latter ones. Ordinarily in summer a good ink appears to be black after a few weeks, but in winter the same intensity of color requires from one to several months; in both cases the ink is still far from deep black and is yet a long way from the final result.

With proper magnification and illumination the apparent black color which first develops is seen to be not black but rather a bluish purple at its densest portions, and shades off to light blue in the very thin areas. Gradually, the blue color disappears and the purple darkens until the ink finally becomes black without any purple or blue color in it.

This latter process is quite slow, and the inks investigated by Osborn<sup>26</sup> in 1928 required a much longer time than those formerly used. In 1910 about 14 to 24 months were required for this change but in 1928 it often required twice as long for some of the inks to lose the blue-purple color.

Osborn<sup>27</sup> proposed that these color changes be employed to form an estimate of the possible age of iron nutgall ink writing, and for this purpose he designed a color-comparison microscope (Chap. 43). This instrument is simply a low-power microscope with two body tubes and two matched objectives; right-angle prisms bring the image of each objective into one-half of the field of the ocular. In this way it is possible to juxtapose two specimens for comparison. The body tubes of the microscope have slots through which Lovibond tintometer glasses may be inserted. Diffused sunlight is used as the source of illumination for the subject matter under examination. When the tintometer glasses are used, a pure white background must be placed under one objective. If the ink line selected



for examination is brought into view by the other objective, it is possible to study and compare its color by inserting the proper combination of red, yellow, and blue tintometer glasses in the body tube of the other objective (Fig. 223).



**Fig. 223. Color comparison microscope and Lovibond tintometer glasses.**

For future reference it is necessary that a note be made of the particular portion of the ink line which is examined. This may be done by describing the word and letter used; the specific portion may be located with coördinates obtained by accurate measurement from some arbitrary origin such as a period of a sentence. If this precaution is taken, no difficulty will be encountered in relocating the exact section of the ink line which was the subject of the examination.

The chief value of the color-comparison microscope is that it offers a means whereby it is possible to compare the color of two iron nutgall writings alleged to have been made with the same ink and at the same time, or to compare writing with itself over a period of time. In the former case any significant variations of color, as determined by a direct comparison of the two writings



or by an indirect comparison of each with the Lovibond glasses, would be helpful in establishing that the writings were not made at the same time. It need hardly be mentioned that in these comparisons a blotted portion is not to be compared with an unblotted portion, and that other conditions must also be similar, i.e., the inks are on the same type and quality paper. In examining ink writing over a period of time, any change in color (i.e., from light blue or purple to black or an increase in the saturation of the black) indicates that the color of the ink has not reached its greatest intensity, and the ink therefore is not very old in years. In the usual case, where an alteration of an old document is made only shortly before it is to be used, this may be quite valuable information. Thus a document (or part of a document), alleged to have been written a great many years before the time it was submitted for examination, may be shown to be of recent origin if the tintometer values obtained in the examination are significantly different from those obtained when the document is examined subsequently, i.e., after several weeks or months.

A word of caution should be given at this point for those who have never made color comparisons and therefore may be under the impression that this is a simple matter. The difficulties of such an examination will be recognized by any individual who has made many color measurements. Even the simple problem of the comparison of intensities of two solutions of the same color is quite difficult when it is attempted visually. The more complex problem such as we have in the comparison of dried ink writing involves even greater difficulties. In this latter case it is necessary to select a combination of three colored tintometer glasses out of several thousand possible combinations. It is hoped that the resultant color of the final selection matches that of the ink line. As a matter of fact, however, the color of the ink line is usually not uniform throughout a given area, but is a heterogeneous mixture of the several pigments present, so that the portion to be matched is not even clearly defined in many cases. It is possible that future research with reflectance or transmission spectrophotometric measurements may provide the means of eliminating these difficulties (see Chap. 43). The work of Casey and Bailey has shown that the color of ink stains on paper may be compared spectrophotometrically.<sup>28</sup> An extension of this work will, no doubt, permit a comparison of the colors of ink *lines*.

### 13. DIFFICULTIES, LIMITATIONS, AND PRECAUTIONS

The many practical difficulties, over which the document examiner has no control, are usually sufficient to defeat any attempt at the estimation or comparison of the age of writings. In some cases however, the methods enumerated in sections 14–17 may prove helpful. In general they are applicable only to iron gallotannate inks. At the appropriate places in the text certain precautions are pointed out for the guidance of those who wish to employ a particular method.

Many factors influence the appearance of ink writing. Consideration therefore must be given to these factors since they may also influence the results obtained in the various examinations suggested below. The factors are:



### **The Condition of the Ink**

Did the ink contain sediment? What was its fluidity? Was a blotter used? What was the type of pen and its condition? Was it a steel nib pen or fountain pen? Was there any old dried crust on the nib? Did it regulate the flow of ink on to the paper so that a more or less even distribution was obtained?

In general, anything that influenced the volume of liquid ink per unit area of paper is of importance in that the appearance and condition of the writing is affected by any variations.

### **Composition of the Ink**

The variations in chemical compounding of ink by different manufacturers or even by the same manufacturer result in differences in appearance of ink writing, even though all other conditions were the same. In particular, if the proportions of the principal ingredients (ferrous sulfate, gallic and tannic acid) are not within certain limits, the writing may become prematurely rusty; this condition should result (for good inks) only after the writing is extremely aged and the organic compounds have completely decomposed, leaving only the comparatively stable inorganic constituents.

### **The Kind of Paper Used**

Did the paper contain aluminum hydroxide sizing, or alkaline loading material such as calcium carbonate that would hasten the oxidation of the ink by reacting with the acid in the ink? Variations in absorption by papers also affect the appearance of ink writing.

### **Storage Conditions**

Under what conditions were the writings kept? Exposure to light and dampness would result in an older appearance than that which a writing would have if it had been stored in a dark and dry place.

Since it is impossible in most cases to know whether these factors are similar in the case of two documents which are to be compared, it should be obvious that great caution must be exercised in expressing an opinion of the comparative ages of the two writings. In certain cases it may be possible to do so, but the conditions listed above must be known to be similar, and in general the results obtained in the examination must be considerably different before the document examiner is justified in submitting a report that two writings were not made at the same time.

## **CHEMICAL METHODS FOR THE ESTIMATION OF THE AGE OF WRITING**

### **14. TIME OF REACTION**

Mitchell<sup>29, 30</sup> suggests that for iron gallotannate inks a 5 per cent oxalic acid solution is the reagent to use in making the tests upon the writing in question.



The method is based on the relative rates of the phenomenon observed; these rates are said to be dependent upon the age of the writing.

In recent writing the reagent (oxalic acid) bleaches the black portion (iron tannate) of the ink and the provisional dye spreads out on the paper; in old writing the same reagent requires a much greater time to bleach the black portion of the ink and little, if any, diffusion of the blue dye occurs. The reason advanced for this latter result is based upon a change of the iron tannate from a soluble to a resinous and more complex form which encloses the provisional dye-stuff so that the reagent is unable to quickly affect, or react with, the constituents of the ink. Thus in recent writing all the pigments are affected and diffusion is general, while in aged writing the diffusion occurs only on the surface of the ink and does not affect all the pigments of the ink. Any estimates of the age of ink writings formed from the data on the rate of reaction and the amount of diffusion are valid only when the differences are pronounced. Of course, it is also necessary that the inks be of the same type and the *ink density*, as shown by low-power microscopic study, be approximately the same.

Another method which has been suggested<sup>31</sup> also depends upon the time required for a very dilute solution of an oxidizing agent, such as hydrogen peroxide or bleaching powder, to make the writing disappear. It is claimed that with a bleaching powder solution of specific gravity 1.001, the time required for known writing 1 day old to disappear was 6 minutes; 6 months old writing required 9 to 12 minutes; 1 year old writing required 20 minutes; older writings reacted as follows: 2 years — partly disappeared, 14 years — slightly affected, 22 years — hardly affected at all, in 20 minutes of reaction time. Of course, the difficulties and limitations heretofore mentioned also obtain in the use of this method.

## 15. BLUE DYE AS EVIDENCE OF AGE

C. E. Waters<sup>32, 33</sup> studied the possibility of using the provisional coloring matter, i.e., the blue dye that is added to the ink, as a means of estimating the age of writing. This investigation was brought about because of a common belief that the presence of a blue dye in writing proved that the ink could not be more than fifteen years old. As a corollary, the disappearance of the dye proved that the ink writing was over fifteen years old. Waters used writings of known ages in his investigation. He found that the oldest writing to contain a blue dye was made in 1881 and was fifty-two years old at the time of the tests. Some later writings were found that did not contain any blue dye.

Mitchell<sup>34</sup> claims that aniline blue dyes were employed in the manufacture of blue-black inks from about 1880 on. He traced the presence of a blue dye pigment in the writing of old ledgers back for thirty-five years, the oldest writing having been made in 1885.

As a result of these studies it may be said that the presence or absence of a synthetic blue dye in ink writings is not a dependable criterion for the age of writing made after 1880. If an aniline blue dye is found in writing alleged to



have been made before 1880, considerable doubt is created as to the correctness of the assertion; if alleged to have been made before 1856, the year in which Perkin prepared the first synthetic dye, the allegation is unequivocally false.

## 16. CHLORIDE ION AND SULFATE ION DIFFUSION AS EVIDENCE OF AGE

Mezger, Rall, and Heess<sup>35, 36, 37</sup> proposed to use as a means of estimating age the rate of diffusion of the chloride ions or sulfate ions of the acid that is added to delay sedimentation in nutgall and other inks. Sulfate ions also are present because of the ferrous sulfate used in compounding. The halo of the developed chloride or sulfate picture (Chap. 37) depends upon the diffusion or migration of the ions, which in turn depends upon elapsed time; the longer the time, the greater the diffusion and the greater the halo spread. Other investigators,<sup>38, 39</sup> employing the method for chloride ions, examined various commercial inks and reported that it was unreliable for determination of the age of ink writing the previous history of which is unknown.

If one is able, however, to determine under what conditions\* the original writings were supposed to have been made and the conditions under which they were subsequently kept, it may be possible, in certain cases where these conditions are similar, to compare the ages of two writings by this method. The most suitable writings for comparison are those alleged to have been made at the same time and on the same piece of paper. Counterclaims that some of the writing was added some time after the original writing may be investigated fruitfully by chloride and sulfate picture methods.

## 17. THE OXIDATION OF FERROUS TO FERRIC IRON AS EVIDENCE OF AGE

Rhodes<sup>40</sup> suggests that for iron nutgall inks, the rate of oxidation of ferrous iron to ferric iron be used as the basis for estimating the age of writings up to twenty days, after which time the oxidation is substantially completed. The reagent, a 1 per cent solution of  $\alpha, \alpha'$ -dipyridyl (more correctly, 2, 2'-bipyridyl) in 0.5 *N* hydrochloric acid forms a pink-colored compound with ferrous ions, but no color is developed by ferric ions. The reagent is applied to the ink line for one minute and then picked up on filter paper. The pink color produced by the reaction of the reagent with the ferrous iron completely separates from the blue zone caused by the provisional dye in the ink, to form a zone of its own. A series of color standards must be freshly prepared for comparison with the coloration produced when the ink is tested. The color standards are prepared from an aqueous solution of ferrous ammonium sulfate containing 0.00705 g of iron per g of solvent. The series of standards is prepared by placing quantities of solution, weighing from 0.001 g to 0.03 g, on pieces of filter paper, adding a drop of the

\* By this is meant: Was the same paper used? The same ink? Was one writing blotted, the other not? Were they stored in an identical manner as to light, dampness, heat, and circulating air?



reagent and a drop of water. The color comparisons are made when the spots are dry.

In practice, then, the method resolves itself into choosing similar ink lines for comparison and then, by means of prepared standards, comparing the amount of ferrous iron transferred to a filter paper in each case. The method, therefore, is qualitative or at best semiquantitative. The same precautions heretofore mentioned must be observed in this case, namely, the differences should be very pronounced before one is able to state that two writings, claimed to have been made at the same time, were not written at the time alleged. Other sources of difficulty in the Rhodes method are:

If indigo was used as the provisional color the method may not be used; however, the usual synthetic provisional dyes do not interfere.

Those inks that initially contained a smaller quantity of iron than usual cause complications. In these cases the conversion of ferrous to ferric ions is accomplished in 15 days (instead of 20). Thus if traces of ferrous ion are found, it is necessary to make a microdetermination of the quantity of iron present.

Although Rhodes, in the introduction to his article, makes the claim that his method is based upon the rate of oxidation of ferrous to ferric ions, we have seen that in practice, with unknown written documents, this is not so. Any differences in ferrous iron between two writings may merely reflect differences that existed originally in the iron content of the two inks or in the amount transferred to the filter paper. A more satisfactory procedure would be to determine also in every case the total quantity of iron transferred to the filter paper. This information would then be used for the calculation of the ratio of ferrous to total iron. This factor would be a better means of comparison than ferrous iron alone. If sufficient writing is available for test purposes, several examinations should be made, the average result computed, and used as the basis of comparison.

This method would be most suitable for an examination of two recent writings alleged to have been made at the same time, with the same ink, on the same paper. Close agreement in the ferrous to total iron factors would indicate that the writings were made at the same time, whereas a considerable difference in these factors would indicate that they were not made at the same time.

### **18. ARE THE INKS FROM THE SAME BOTTLE?**

It is obvious that if it were possible to demonstrate that two ink writings were made with the same ink from the same bottle, many difficulties which ordinarily beset the document examiner would be lessened considerably. The methods that have been suggested as a means of obtaining data pertinent to this question are physical in nature.

The first method proposed was that of Osborn<sup>41</sup> who listed several ways in which two ink lines written with different inks of the same type may differ. The possible variations in the appearance, as determined by visual and microscopic examination are:

- (a) Color — Differences in this factor are determined by comparison of the general appearance, range of contrast between light and dark portions.



manner of variation of tints, secondary colors (as viewed obliquely by reflected light), and gloss or sheen of the two lines.

- (b) Characteristics of margins of strokes — smooth or ragged?
- (c) Degree of penetration of ink into paper.
- (d) Amount of sediment (particularly in blotted or thin portions).
- (e) Characteristics of color in blotted portions of writing.

When these possible variations are considered in conjunction with the factors that influence the appearance of ink writing on paper (v.s., sec. 13) it is easy to understand why Osborn's suggestions may be useful in distinguishing between two writings made with the same type (but not the same bottle) of ink. Of course, two writings made with the same ink, but on different types of paper and with different pens, may also appear to have been made with two different inks; therefore the method is perhaps best suited to show that two writings were made with the same ink. It should be obvious that it is very difficult, although not impossible, to duplicate all the minor differences that may exist between two writings unless the ink came from the same bottle, and all other conditions were similar.

Mitchell and Ward suggest<sup>42, 43, 44</sup> that the sediment, which occasionally is found in ink lines, may be sufficiently characteristic to identify two writings as having been made with ink from the same bottle.

Several reasons are advanced by these authors for sedimentation in the ink container and in the dried ink stroke. They may be classified as follows:

- (a) **Sediment Resulting from Substances Thrown Out of Solution** — With age it is normal for some sediment to settle to the bottom of the ink container. Precipitates are also formed in uncovered ink containers after too much water has evaporated. Incorrect compounding of the ink also causes precipitates to form. Thus an excess of ferrous sulfate or too high a percentage of gallic or tannic acid may result in sedimentation. Permitting the pen to remain in the ink well may have the same effect as excess ferrous sulfate. The alkali of a glass ink container may affect the *pH* (equation 2) and cause some sediment to be deposited. These precipitates may be transferred to the pen and then left as a deposit in the ink writing.
- (b) **Sediment Resulting from Extraneous Materials** — A bottle of ink may be contaminated by dust or plant debris such as pollen and starch grains, insect fragments, mold, fibers, etc., which are floating in the air. Ward<sup>43</sup> claims that the insoluble matter in ink writing, because of its characteristic structure and arrangement as observed microscopically, may be of considerable value in identifying ink as coming from a particular bottle or receptacle or in indicating the common source of the writing on two or more different documents. It should be pointed out that if an uncommon material is found as a sediment in both writings, a high probability exists that both were made with ink from the same bottle; if the sediment



is the precipitate of a constituent of the ink, the probability is not nearly as great that the writings were made with ink from the same bottle.

The technique used in this examination requires that an ink line be examined under a microscope at medium power (100X). Those portions of the ink line which were blotted or which for some reason contain less pigmentation should be selected as the place of examination since the sedimentation may be more easily observed at these points. A filter, made from the same type of ink but diluted with water, is used to eliminate the color of the ink line and to reveal the sediment as dark matter against a light background. Ward claims that ferric tannate in fused phenol makes a superior filter medium to that suggested above. Photographic filters are also quite useful for this purpose.

As in all ink problems it would be wise to exercise caution in employing these data as the basis for any positive findings that two writings were made with the ink from the same container or were not so made. Only when the results are unique may the examiner make categorical statements about his findings.

### EXERCISES

1. The student should obtain several commercial samples of each type of ink and perform the tests using the reagents shown in Table 23. It would be well to conduct the tests in test tubes as well as on the dried writing.

2. The student or apprentice document examiner should obtain several samples of different brands of iron nutgall (blue-black) ink. A file of known writings of different ages should be started and maintained. The same pen and ream of paper should be used in preparing these specimens. After a sufficient time has elapsed, the various tests for estimating the age of ink writing should be employed in the examination of the known or prepared samples.

Other samples of writing of known age such as dated letters, written reports, and old lecture or stenographic notes may be collected. In these specimens the type of pen, paper, and constituents of the ink will more closely approximate the situation that confronts the examiner when an unknown document is submitted for examination. Examine these samples as though they were of unknown age. The results obtained for each set of unknown writings should be compared with each other and with the known facts regarding their ages.

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# CHAPTER 35

## ERASURES AND OBLITERATIONS

The detection and deciphering of alterations is one of the major problems in document examination. Checks, wills, insurance policies, passports, licenses, birth certificates, and official records are often the subjects of alterations made with criminal intent to defraud or deceive. Documents not concerned with crime are also submitted to the laboratory for the purpose of making legible writing which has become faint because of wear, exposure, immersion, or other abuse.

For the purpose of this chapter, alterations are divided into two classes: erasures and obliterations. *Erasures* will be understood to mean removal of writing from paper. The term *obliterations* will refer to the obscuring of writing by superimposing ink, pencil, or other marking material.

### 1. TYPES OF ERASURES

An erasure may be made by mechanical or chemical means. Rubber pencil erasers, ink erasers, and scratch knives are familiar examples of abrasive materials that are used for mechanical erasures. Chemical eradicators usually consist of two compounds: an oxidizing agent which decolorizes or bleaches the provisional blue dye of iron nutgall inks, and another agent which removes the ferric tannate by change of *pH*, reduction, or complex ion formation. It is not possible to eradicate chemically inks of the carbon black (chinese) and nigrosine type. Other classes of inks can usually be eradicated chemically.

### 2. TYPES OF OBLITERATIONS

Occasionally a person crosses out or obliterates immediately after writing. In a case of this type the writing pigment and the covering pigment generally are the same. In other cases the two pigments may be different. Thus pencil may be obliterated by ink, or one ink by another ink of different color; crayon may be smeared over pencil or pen writing. Other inscriptions such as those made with typewriters and rubber stamps,\* as well as printed matter in general, e.g., letterheads and return addresses, are also found obliterated, usually with a pigment different from that of the original writing.

\* Dates, endorsement forms for checks, and receiving time for mail are common examples of rubber stamp inscriptions.



### 3. METHODS FOR DETECTING THE PRESENCE OF ERASURES

Erasures that were made by mechanical means are usually obvious and easily detected by visual inspection (cf. Fig. 224a). The removal of part of the paper makes the erased area more translucent when held before a strong light. Examination under oblique lighting or with a Greenough binocular microscope may be necessary to discover a skillfully made erasure (Fig. 224b). When petroleum ether (benzine), carbon tetrachloride, or other organic solvent is dropped onto a paper, it spreads and moistens the paper until it reaches the

Account No. \_\_\_\_\_

SAVINGS  
ASSOCIATION

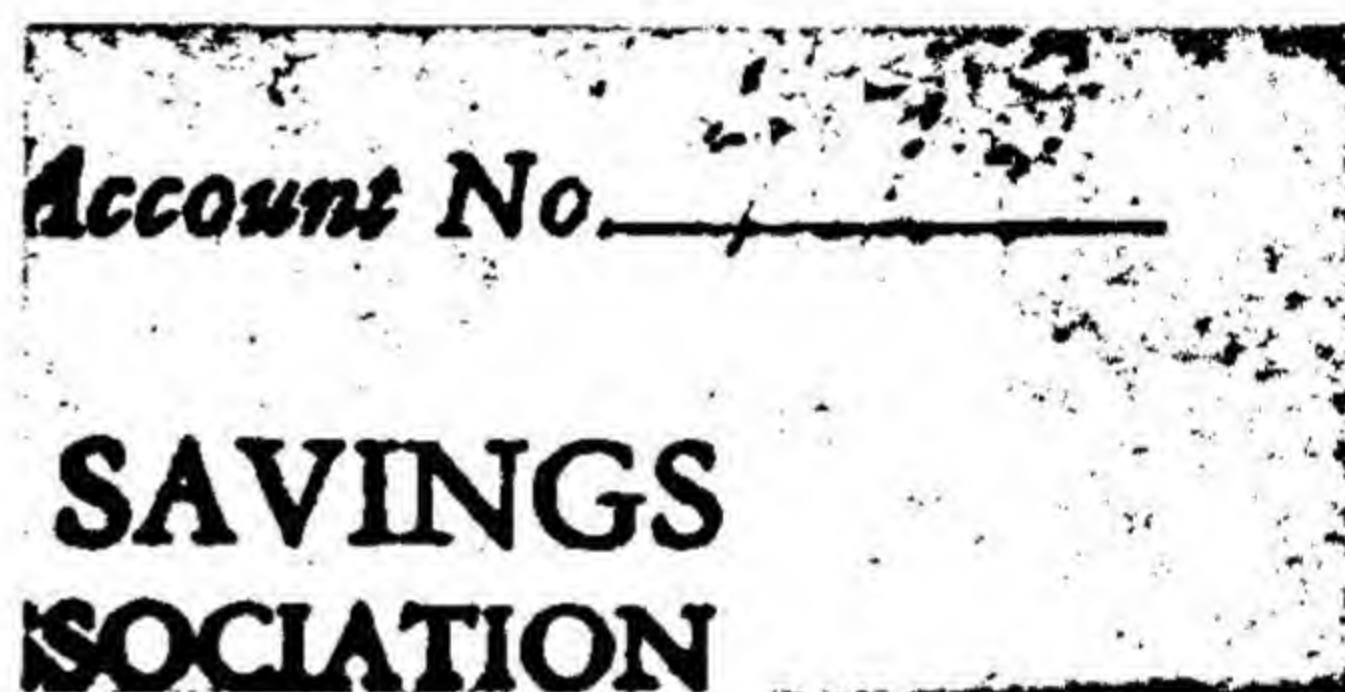
(a)



(c)

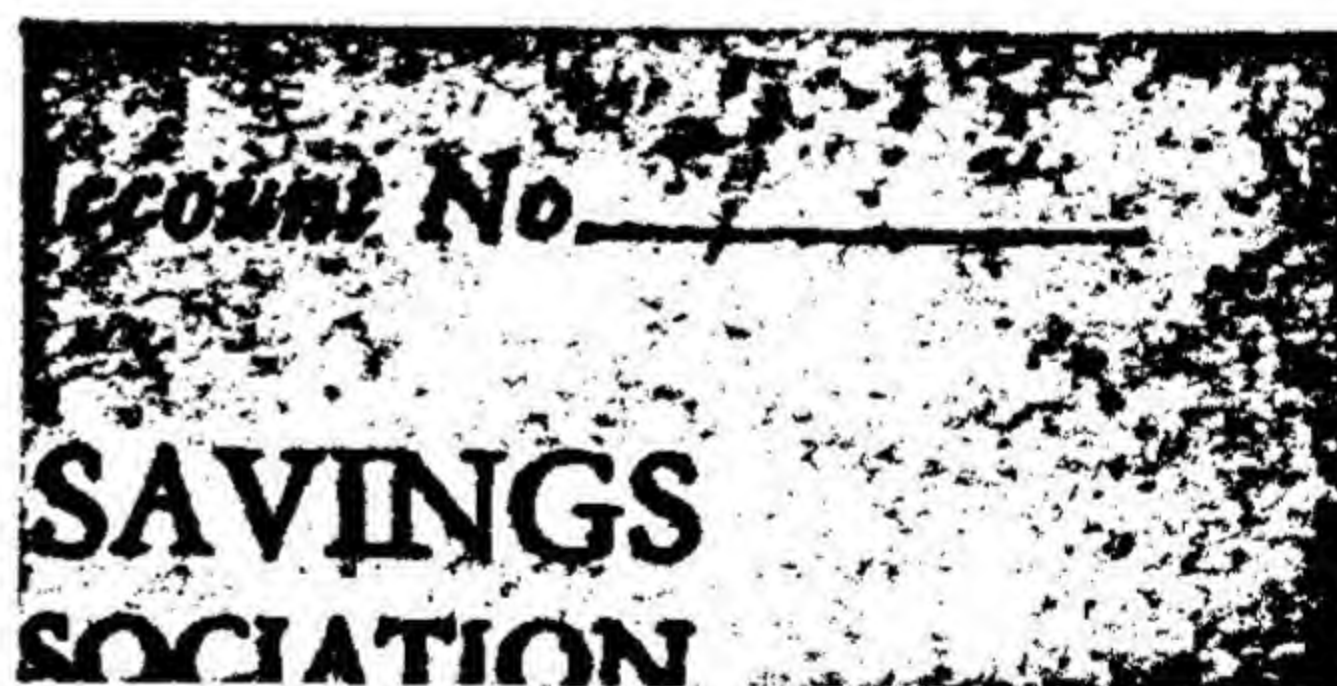


(b)



(d)

Fig. 224. A skillfully made erasure which is not detectable by a casual inspection. Photographed (a) as seen normally; (b) as seen in oblique lighting; (c) by means of a process film transparency; (d) with process pan film and a Wratten 21 filter; (e) with infra-red film and a Wratten 70 filter.



(e)

erasure, where, instead of moistening this area also, it proceeds to travel along the boundary and later penetrates the erased area.

If the erased area was written over with ink, a rough, *feathered* line commonly is present instead of the usual smooth line. This, however, is not in itself sufficient indication that an erasure has been made, since poor quality sizing may be the cause. If this latter condition exists, the feathered ink lines will usually be found throughout the entire text and will not be confined to a small area. Thus, physical evidence other than feathering must be found before the presence of an erasure is established. A photographic method that is sometimes of value consists of using the paper as a negative and contact printing through it



on a process film, which is used in place of photographic paper. Film is used because of the greater contrast that is possible and because it is more satisfactory to examine the film by transmitted light than to examine a regular print by reflected light. In addition, printing the (process film) transparency on No. 5 photographic paper may also be used to further increase the contrast (Fig. 224c). Viewing the paper under ultraviolet light may disclose an erasure by a difference in fluorescence or appearance caused by a disturbance of the surface fibers of the paper when made mechanically, or by a discoloration or stain when made chemically. However, if the eradication was not made recently or if the area was carefully washed with distilled water, it is possible that ultraviolet light may not reveal the presence of the eradicated area. Ink eradicators may also cause the color and appearance of the paper to be changed so that mere visual inspection will disclose the fact that an erasure was made.

Other methods are available when it is suspected that an ink eradiator was employed. These methods are based on chemical tests for a constituent of the eradiator, and will be discussed below in the following stepwise procedure that is recommended as a systematic method of examination:

### **Physical Methods**

#### *VISUAL INSPECTION*

Artificial light, varying in intensity and reflected at different angles, is used. Oblique lighting is particularly helpful. Transmitted light is also very useful. Mechanical erasures and sometimes chemical erasures are disclosed by this simple examination.

#### *ULTRAVIOLET LIGHT*

This is useful in disclosing both types of erasures — mechanical or chemical.

#### *PHOTOGRAPHY*

The methods involving photography (printing the paper as a negative on process film) or organic liquids (petroleum ether) are useful in confirming any doubtful results of the visual and ultraviolet light examinations. These processes may also be used as independent methods of examination. The document may sometimes be profitably examined with various photographic filters.

### **Chemical Methods**

The remaining methods are chemical in nature, and in some cases may be used to confirm the results obtained by the physical examination, or may be used independently. The type of chemical eradiator may be determined in some cases. This information will be useful if an unusual eradiator, such as a stannous chloride or titanous chloride was employed and the eradiator found in the possession of the suspect was also of the same type.



### *UNIVERSAL INDICATOR PAPERS*

There are available commercially several wide-range *pH* indicator test papers\* that may be used to determine approximate *pH* values. Merely pressing a piece of moistened indicator test paper against the suspected area of the document is sufficient to determine if any acidic or basic substance has been used. Many eradicators require an acidic solution, i.e., a low *pH* value, in order to function. A comparison test must also be made on a part of the paper or document which is not close to the suspected area.

### *STARCH-IODIDE PAPER*

When starch-iodide paper is moistened and touched to an area on which a hypochlorite eradiator was recently used it turns blue. This test is based on the oxidation of the iodide to iodine and the formation of the characteristic blue color with starch. A control test must be made on an untouched area of the paper.

### *AMMONIUM SULFIDE VAPOR*

If a stannous chloride or other inorganic reducing reagent was used to eradicate the ink writing, ammonium sulfide vapor will turn the area a dark brown-black color and will not affect the remainder of the paper. The paper must be observed carefully during this process, for it is possible that the erased writing will also be developed. If this occurs, the developed writing should be photographed.

## **4. PHYSICAL METHODS FOR RESTORING ERASED WRITINGS**

The deciphering of erased writing requires considerable patience and resourcefulness. Although the choice of a successful technique is ordinarily unpredictable, one should not rely merely on randomly selected favorite methods. A systematic procedure should be followed, the methods least damaging to the document being employed first. Many of the methods already prescribed for the detection of erasures are effective also in revealing the nature of the writing itself. In general, the means employed in physical methods are magnification, manipulating sources of visible radiation, invisible radiation, fluorescence, color contrast, and tonal contrast.

### *VISUAL AND MICROSCOPIC EXAMINATIONS*

The paper is illuminated with light varying in intensity and is moved so that the light is reflected at all angles. In particular, the inspection should be made very carefully when the angle is oblique. Erased pencil writings are sometimes made legible by oblique lighting.

The ordinary hand glass and the linen tester or pick glass that are used in fingerprint work may sometimes be useful for this work. The Greenough

\* Accutint *pH* test paper (No. B) — Sargent & Co. Wide-Range Indicator Paper (No. 21486) — Central Scientific Co. Gramercy *pH* Range Finder Paper-Eimer and Amend.



binocular microscope, however, will be found most satisfactory. Small fragments of writing pigment can be seen when magnified. Thus, it is sometimes possible to form a pattern or to establish a connection mentally among the various pigment particles and thereby decipher, letter by letter, the original writing. In the laboratory one soon learns from experience that usually only certain words, or parts of a word, become visible by this method. However, when studied in connection with the results achieved by other means it may be possible to restore satisfactorily the original writing.

### *ULTRAVIOLET LIGHT*

Some colored inks are fluorescent. It is possible that an erasure made mechanically with such an ink has not removed all of the ink, so that fluorescent traces may be seen in the interstices of the paper under ultraviolet light. Furthermore, since pencils and inks in general possess characteristics different from those of paper, partly erased or otherwise illegible writing may be restored by photographing any results obtained in this manner. Chapter 17 discusses the procedure employed in photographing objects in ultraviolet light.

### *POLARIZED LIGHT*

The examination of the document in polarized light is most easily accomplished by the illumination obtained from light transmitted through a polarizing screen such as is used in photography. Another polarizing screen is used to view the paper; it is necessary to rotate the latter screen until extinction is obtained. A polarizing microscope at low power can also be used for this purpose. This method is useful for pencil writing, and depends on the presence of small traces of graphite which are not visible in ordinary light but which can sometimes be detected in polarized light. Thus the additional contrast which is occasionally achieved may be sufficient to make the writing decipherable. Any results obtained by this method should be photographed. Chapter 15 discusses the problems involved in photographing objects illuminated by polarized light.

### *PHOTOGRAPHY*

Process film is useful for increasing contrast so that partly erased, illegible (pencil or colored ink) writing may sometimes be deciphered in the photographic print. In addition, panchromatic film, including process pan, must also be considered as a method for the delineation of erased ink writing (Fig. 224d). Of course, the proper filter must be selected for each ink. If other writing remains on the document it is usually possible to determine from the context whether the deleted writing was made with the same ink. If this is the case the filter may be chosen by theoretical and empirical considerations; otherwise, several different colored filters, such as red, yellow, blue, and green, should be tried. The filter is placed before the eye and the erased area is examined. Any filter which enables one to read the writing or seems to increase the contrast is used to photograph the document.



Infra-red film should also be tried if no results are achieved by the above methods. Lead pencil and certain inks are opaque to infra-red rays so that it is sometimes possible by this means to obtain an increase in contrast and render the writing legible (Fig. 224e). Chapter 17 discusses the techniques of photography with infra-red film.

## 5. CHEMICAL METHODS FOR RESTORING ERASED WRITINGS

If the physical methods fail to reveal the nature of the erased ink writing, chemical methods should then be employed. Generally, these methods make use of the residual traces of the ink constituents that remain in the interstices of the paper fibers because they are difficult to remove completely. Unfortunately these methods are applicable only to ink writing as there are no chemical methods available (except iodine fuming) to develop erased pencil writing. Since it is always advisable to alter a document as little as possible in laboratory processing, the methods which are used first should be those that employ easily volatilized reagents; it is only when fuming methods fail that liquid reagents should be applied to the paper. The apparatus used to fume documents are shown in Figs. 229 and 230. The large fuming chamber is most useful when the reaction takes place slowly and the reagent possesses sufficient vapor pressure at room temperature to permit prolonged exposure. These reagents may be aqueous solutions of chemicals such as ammonium polysulfide and ammonium hydroxide, or solids that easily sublime, such as iodine. The smaller apparatus is most useful when the reagent is a gas and must be prepared through double decomposition. Potassium thiocyanate or iron pyrites is placed on the bottom of the Erlenmeyer flask and the dilute hydrochloric acid (about 10 per cent) is added through a separatory funnel. The gas which is generated is pumped out of the flask by squeezing the rubber bulb. The mouth of the funnel is placed over the paper so that the gas comes in contact with the erased area.

The remainder of this section will be concerned with those reagents that are most useful for each type of ink. However, it is advisable that all erasures, regardless of the type of ink, be subjected to the volatile reagents discussed below, since there is a limited number to be tried and they often yield results even though predictions based on theoretical considerations would not indicate their usefulness. Quite frequently these unexpected results may be attributable to traces of iron that are present in an ink, although no iron compound has been added as such. This iron contamination may be caused by impurities in the original compounding materials or to steel pen nibs that may have been used, some iron dissolving each time the nib was dipped into the ink.

It will be seen in Chapter 36 that the reagent which should be used to develop secret writing must be selected fortuitously. In the present case, however, the document examiner is usually fortunate in having some unerased portions of the writing present on the document. Thus by a simple analysis it is possible to determine which is likely to be the most suitable reagent, if the fuming methods fail to develop the erased writing.



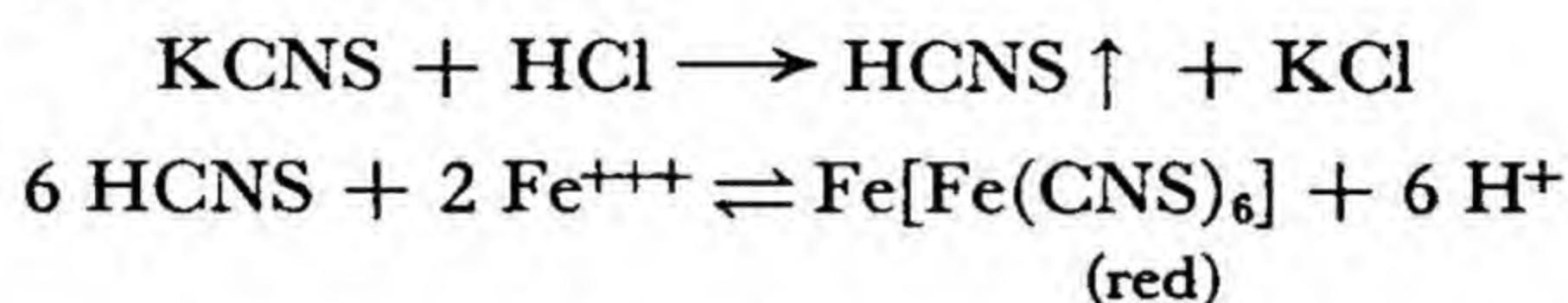
### Gaseous Reagents

The gases below are listed according to their usefulness and the order in which they should be used. In all cases it is advisable to steam the erased area slightly or to have an open beaker of water present in the fuming chamber. This is necessary because moisture assists in the ionization of the reagents.

#### THIOCYANIC ACID — [HCNS]

This reagent was proposed by O'Neill<sup>1</sup> and is more useful than ammonium polysulfide for developing erased iron tannate ink. It possesses many advantages such as great sensitivity, contrasting (red) color of the redeveloped writing, and simplicity of apparatus and technique.

The chemistry of the reaction is:

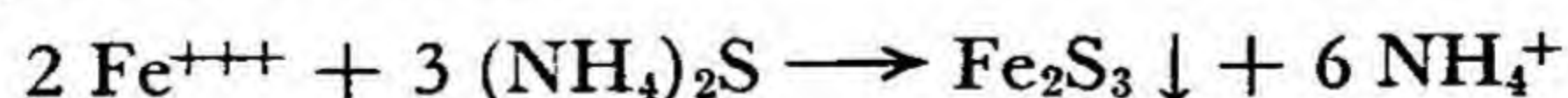


Partly redeveloped writing may be read with greater ease through a blue filter since this increases the contrast of the redeveloped red writing and reduces the contrast of any blue writing that may obscure the results (Fig. 225a).

#### AMMONIUM POLYSULFIDE — [(NH<sub>4</sub>)<sub>2</sub>S<sub>x</sub>]

This reagent is quite useful and has been successfully employed for a much greater time than thiocyanic acid. It is usually necessary to expose the document for several hours in order to have the sulfide vapor bring out the erased writing. This enables one to view the document frequently during the processing so that it is easy to control the development of the writing and, at the same time, to control and keep to a minimum any stains or other objectionable developments that may also start to occur (Fig. 225b). A fuming chamber is used to expose the document to the vapor. This apparatus is cumbersome in the field, hence the more readily portable arrangement of the Erlenmeyer flask and rubber bulb is used when it is necessary to examine a document that cannot be removed to the laboratory (see Fig. 230). Gentle heat may be necessary to increase the sulfide concentration in order to have the reaction take place more rapidly.

The chemistry of the reaction is:



Iron sulfide is ordinarily black but if the conditions are such (as they often are) that a colloidal sulfide is formed, the color may vary from a brownish green to greenish blue. This, of course, is a decided disadvantage when compared with the red color of the ferric thiocyanate and the consequent possibility of increasing contrast by means of light filters.

Residual traces of copper that might be present after certain types of log-wood ink were erased will also form black cupric sulfide when this reagent is employed.

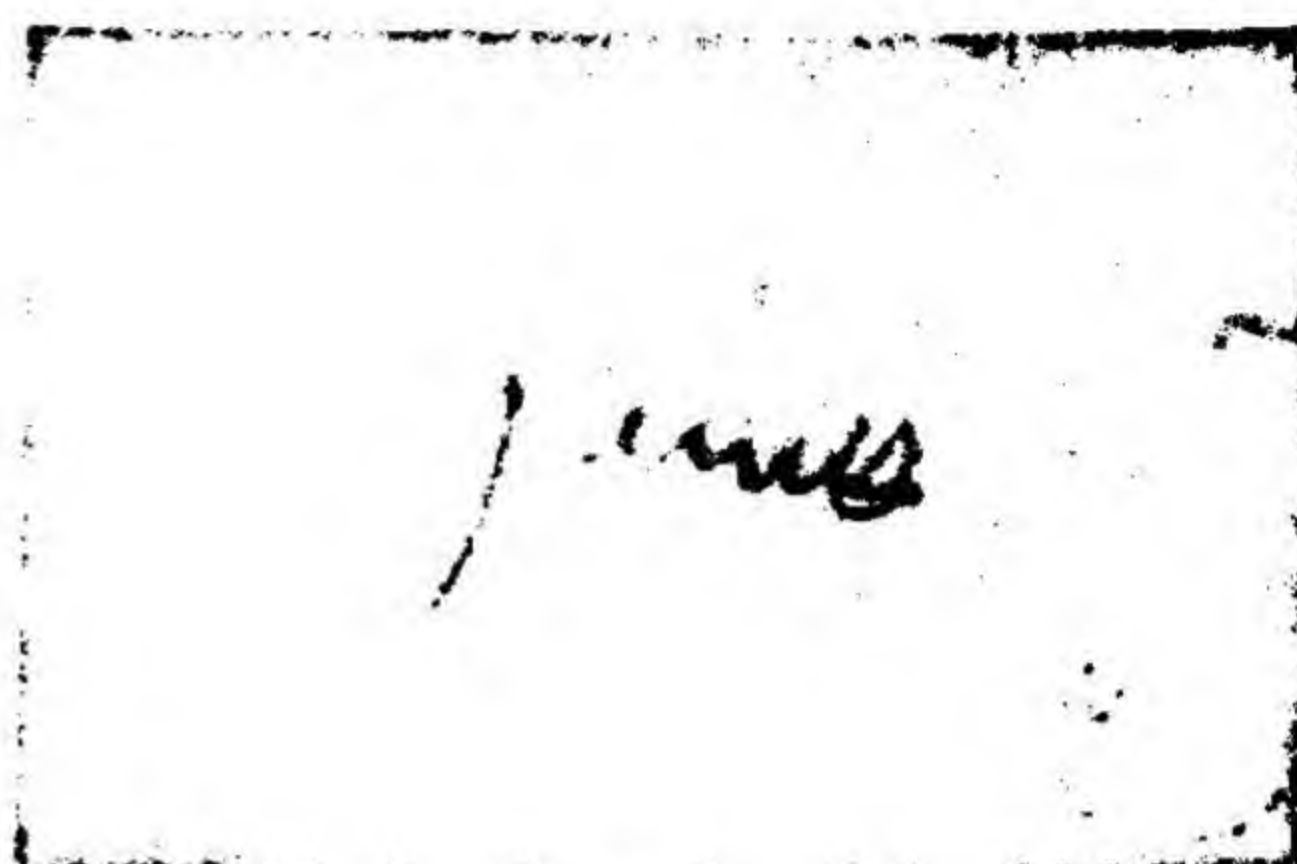


Hydrogen sulfide may be used instead of ammonium polysulfide but it possesses no particular advantage. In certain respects it is a less satisfactory reagent. For example, the increase in hydrogen ion concentration results in a lower concentration of sulfide ions. These concentrations are related according to the solubility product of hydrogen sulfide as follows:

$$C_{H^+}^2 \times C_{S^{2-}} = 10^{-23}$$



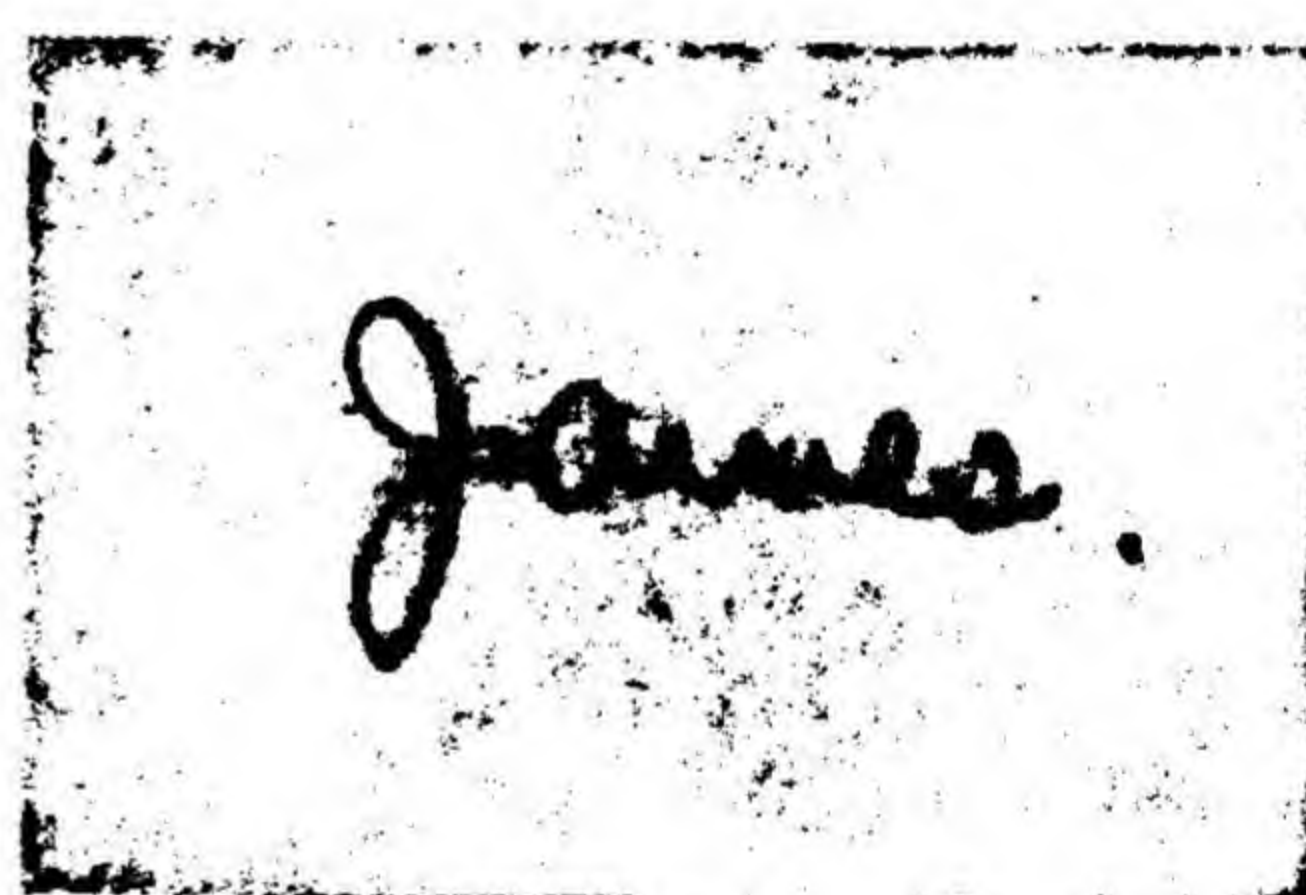
(a)



(b)



(c)



(d)

Fig. 225. Erased writing restored by: (a) gaseous thiocyanic acid; (b) ammonium polysulfide vapor; (c) a solution of potassium thiocyanate; (d) a solution of ammonium polysulfide; (e) ammonium hydroxide vapor.



(e)

## IODINE

Iodine is a solid that sublimates at ordinary temperatures. To fume a document, crystals of iodine are placed in an evaporating dish in the bottom of the fuming chamber. The sublimation may be hastened by heat. However if time permits it is advisable to fume the erasure cold; i.e., after the document is placed in the fuming chamber, the iodine crystals are allowed to sublime at room temperature, with no external heat applied to assist in the volatilization. This may require several hours to a day or so, depending upon the number of

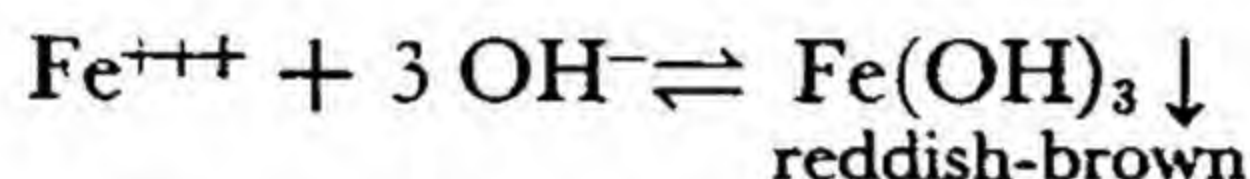


crystals and the temperature of the room. The probability of success is increased if this precaution is observed. In addition a more satisfactory result with respect to staining is also possible because of the greater control the examiner has over this effect.

Iodine is the only chemical method that is available for developing erased pencil writing and, in some cases, erased inks of the chinese (carbon) and nigrosine types. The usefulness of iodine is said to depend upon its differential absorption by the fibers of the paper which formerly contained the writing (see p. 690).

### AMMONIA

Ammonia is a gas that readily dissolves in water to form a solution with weakly alkaline or basic properties. On standing in a fuming chamber an aqueous solution of ammonia saturates the atmosphere of the chamber with ammonia gas. At the erased area on the document ammonia is again dissolved in the adsorbed moisture or the water and absorbed by the fibers of the paper. The resulting basicity in the area enables the residual traces of iron in the erasure to form ferric hydroxide:



The reddish-brown color of ferric hydroxide is usually not intense, so that the contrast developed in the erased writing is not great. Consequently thiocyanic acid and ammonium polysulfide are preferable as reagents for restoring erased iron nutgall ink writing, since these reagents form intensely colored compounds with ferric ions.

The availability of ammonia and the simplicity of fuming recommend its being tried on all erasures that have not been developed by the other gaseous reagents. Either type of fuming apparatus may be used. Steaming the erasure slightly before exposure to the ammonia will assist in redeveloping the writing (Fig. 225e).

### Liquid Reagents

The use of solutions to develop erased writing is not usually advisable, because of the possibility that the document may be stained chemically or altered by smudging of the unerased writing. These objections, particularly the latter, may be controlled or eliminated by careful application of the solution and constant observation while it is on the paper.

If the paper bearing the erasure is not to be used as evidence (for example where an insurance company desires to read an erasure for its own guidance on an application for a policy<sup>2</sup>), or if the paper has no value unless the erased writing is developed, it is advisable to try solutions of suitable reagents after the fuming techniques are found to be unsuccessful. The higher concentration of these reagents makes it possible sometimes to redevelop erasures when all other methods have failed. This success is due to the fact that in the latter case the solubility product of some compound is exceeded (see Fig. 225c and d).



*PROCEDURE*

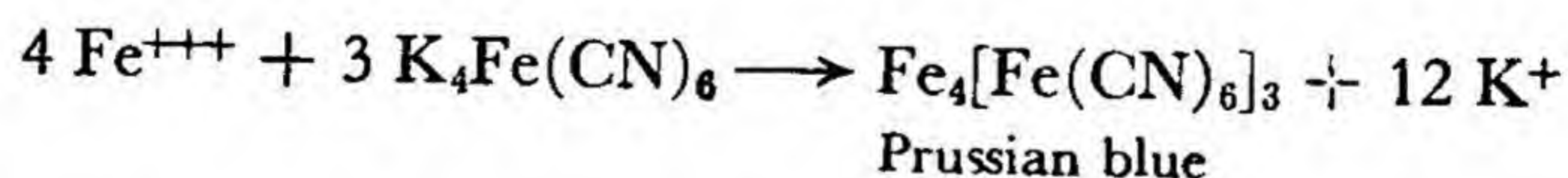
On those documents that bear writing which has not been erased, a simple analysis (Chap. 34) is made of the ink used in the writing to determine the type that was probably used in the erased writing. The reagents which are most likely to be fruitful are selected on the basis of these tests. When no unerased writing is available, the reagents indicated below for iron nutgall inks are used first.

The concentration of the reagents is approximately 20 per cent by weight; they are made by dissolving 20 g of the compound in 80 ml of distilled water. The reagent solution is applied with a capillary pipette to a small area of the erasure. This is carefully observed for the reappearance of the writing and for deleterious effects such as chemical stains. Blotting paper is used to remove the reagent and to keep any excess from spreading to adjacent areas, particularly if there is unerased writing present in those areas. If any writing fails to develop, the reagent is removed with blotting paper and another reagent is tried. If the writing is brought out, it is advisable to photograph the results immediately, for in certain cases the redeveloped writing is transitory.

*IRON TANNATE (NUTGALL) INKS*

Iron nutgall ink is the most commonly used type of ink and fortunately is also the most easily developed by chemical methods. From an inspection of the contents of this type of ink (Chap. 34) it is apparent that the constituent most suitable for development is iron. Thus, many well-known reactions employed in qualitative analysis for the detection of iron compounds are used to renew the erased writing.

Sodium, potassium, or ammonium thiocyanate, sulfide, or hydroxide are useful reagents that may be applied in solution as well as in vapor form (Fig. 225c and d). The chemistry of the reactions was described above. Other reagents which cannot be volatilized or sublimed are also available for use in the form of solutions. For example, potassium ferrocyanide reacts with ferric ion to form a dark colored compound called *Prussian blue*.



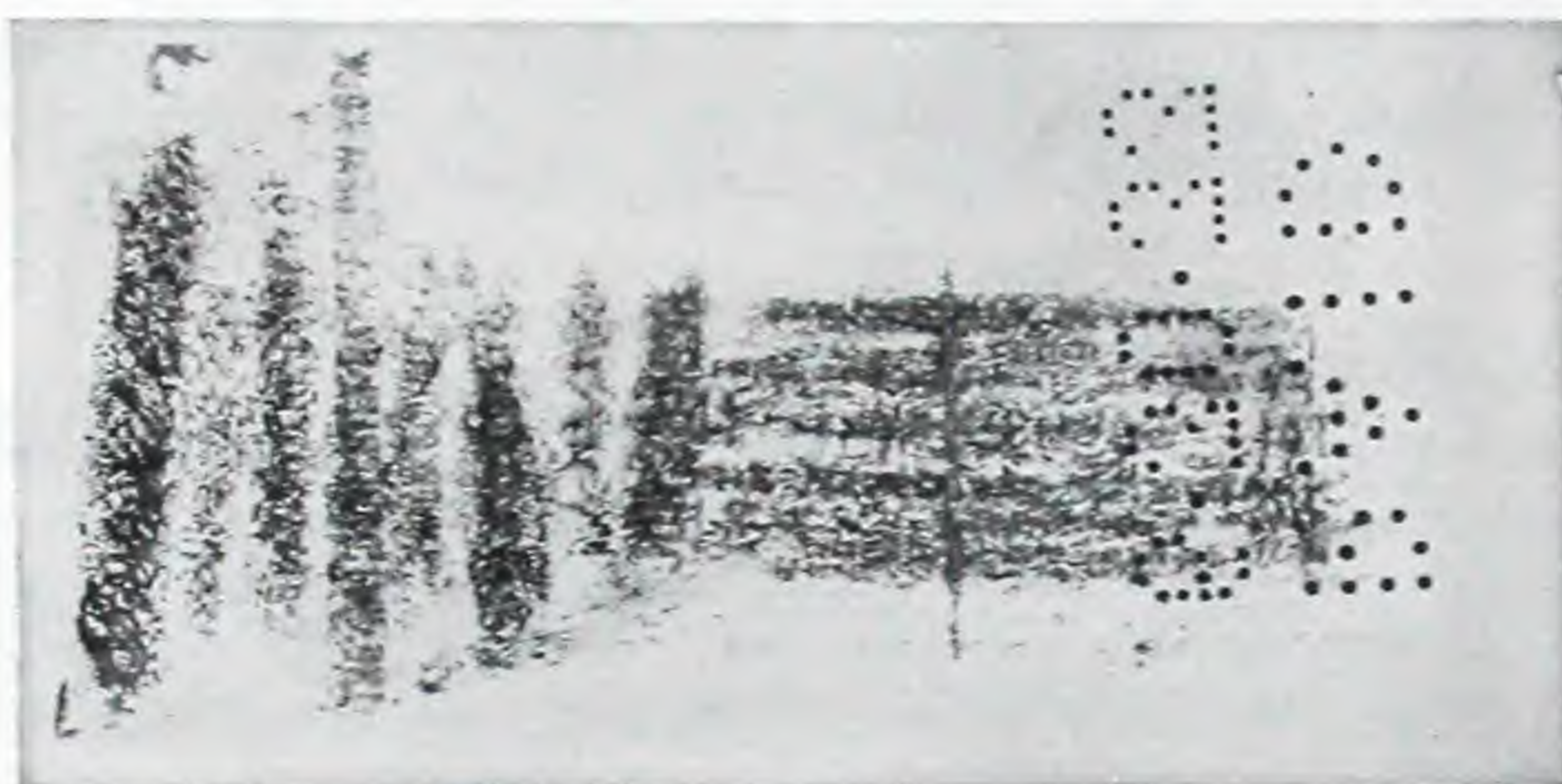
Tannic acid and gallic acid react with ferric ion to form the dark-colored compounds that are called *inks*. The reapplication of these acids, either alone or in mixture with each other or with ammonium thiocyanate may result in the reappearance of the original writing. The chemistry is the same as that explained in Chapter 34.

Chlorides or sulfates may be present in nutgall inks because of the acid that is added. In addition sulfates are always present because of the ferrous sulfate that is used to supply the necessary iron. The methods and chemistry of converting these constituents into colored compounds are discussed in Chapter 37.

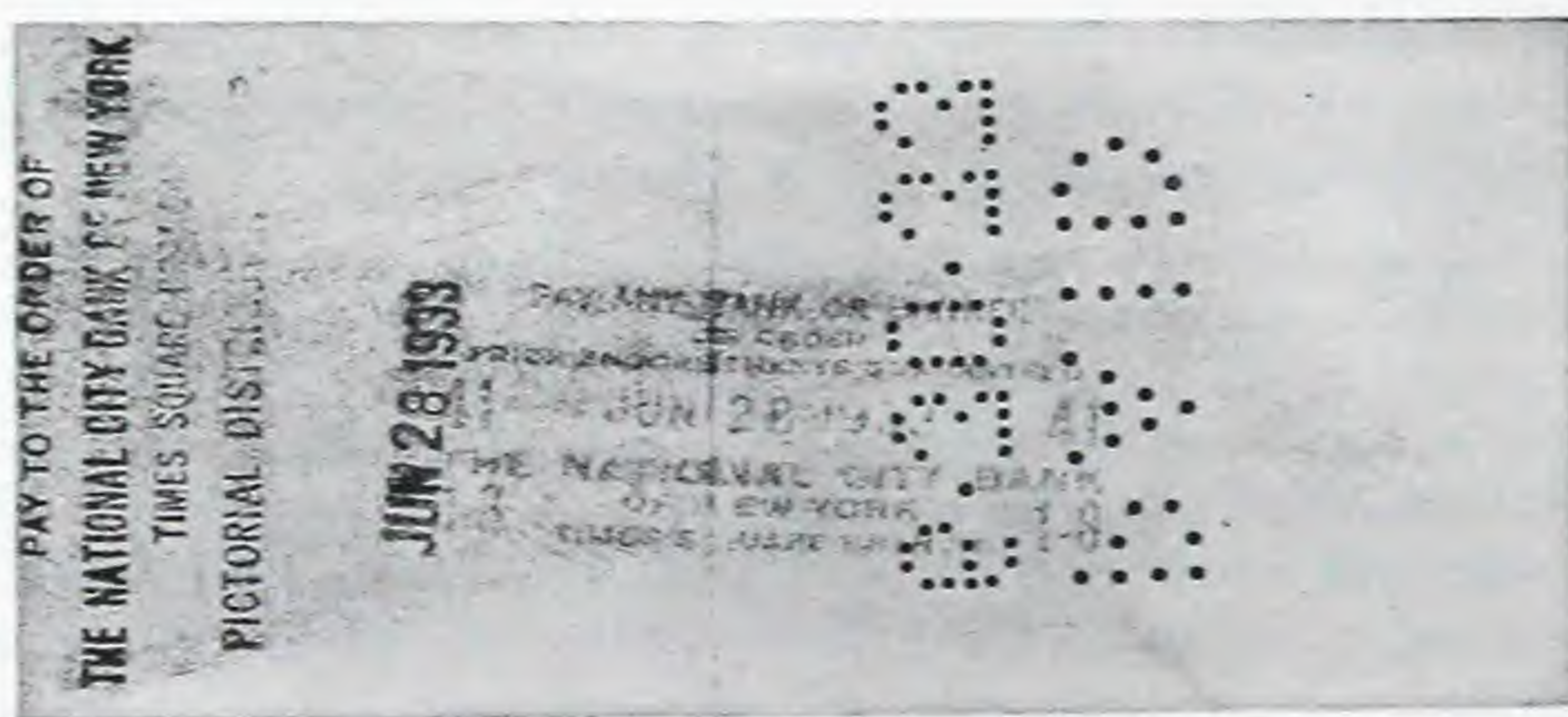




(a)



(b)



(c)

Fig. 226. Endorsements on a green colored check obliterated with a blue crayon. Photographed (a) as seen normally; (b) with process pan film and a Wratten 60 filter; (c) after removal of the crayon with acetone.



### LOGWOOD INKS

Chromium and sometimes copper salts are present in this type of ink. Tests therefore should be made for residual traces of these metals in the erasure if the other writing on the document was made with this type ink. If the type of ink used in the original writing is unknown and if the tests for iron fail, these tests should be tried. Chapter 37 discusses the techniques and chemistry of the methods employed.

Chlorides and sulfates may also be tested for, since acids are added to logwood inks.

### CARBON BLACK (CHINESE) AND NIGROSINE (INDULIN) INKS

The only chemical method available for these types of ink is fuming with iodine. These inks are inert to chemical reagents and must be removed by mechanical methods of erasure. Any inorganic salts that might be present in the original ink are likely to be negligible in quantity after an erasure of this type is made. However, the extreme simplicity of fuming methods requires that they be used even though theoretical considerations offer little hope for success.

## 6. METHODS USED TO DECIPHER OBLITERATED WRITINGS

If the obliteration was made with the same instrument that was used for the original writing, it is usually very difficult to decipher the contents. A procedure that is sometimes successful depends upon a careful optical examination of the document. The unaided eye, a hand magnifying glass, and a low-power binocular microscope are used; in each case the light is allowed to be reflected from all angles and the intensity of illumination is varied. Typewriting that is crossed out with "x" may be deciphered similarly. If the typewriting was deleted with ink, careful visual study, particularly with oblique light, may be helpful. Depressions in the paper which are made by the type may also be seen in this manner. In any event, perseverance and patience are required to reconstruct successfully the original writing. Many times only a few letters or words will be deciphered; the context may make it possible to deduce the rest of the word or sentence.

If the writing was obliterated by means other than with the pigment of the original writing (Fig. 226a), there is a much better chance of its being restored. In addition to the visual and microscopic examinations, photographic techniques

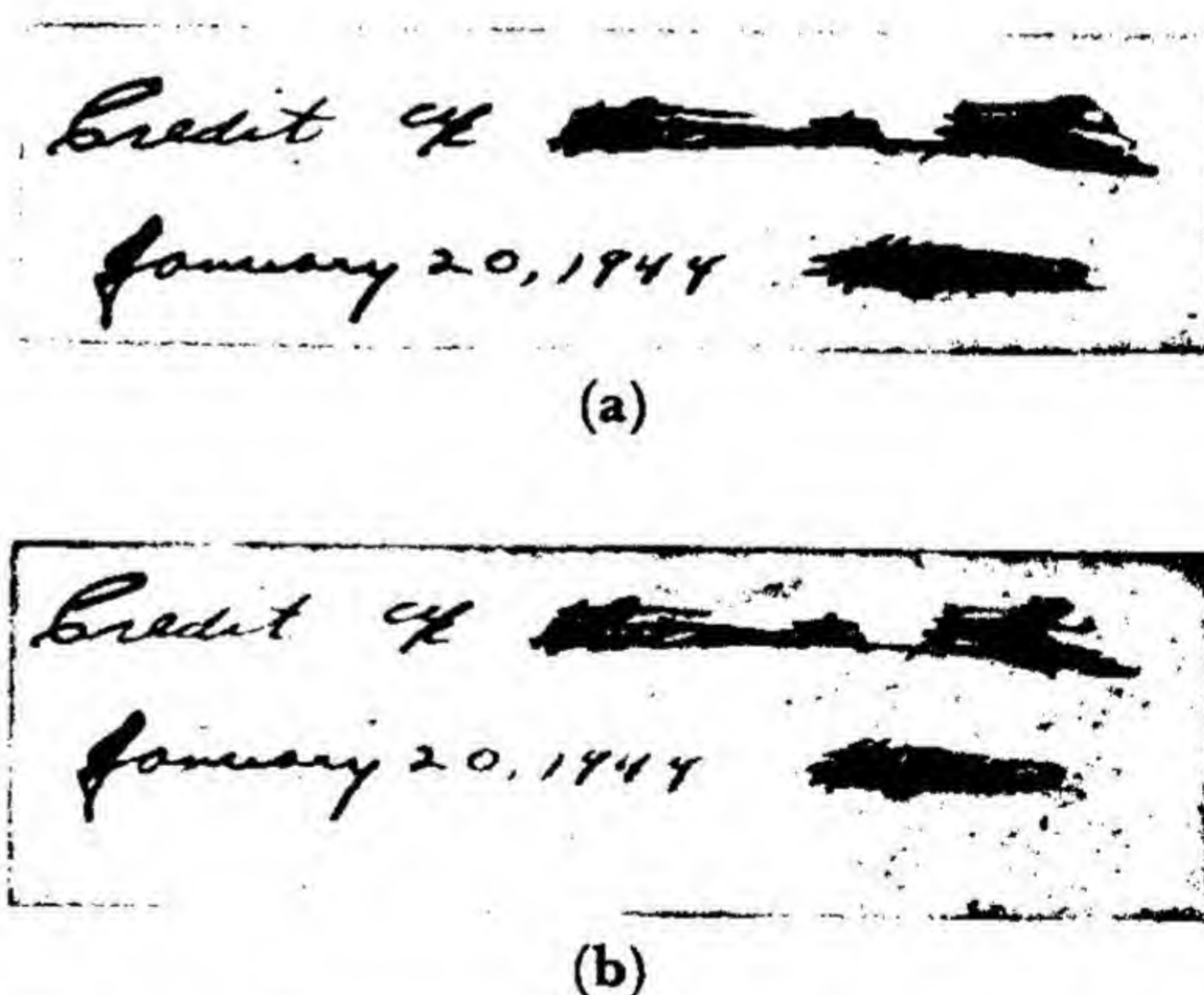


Fig. 227. Restoration of an obliterated writing in which two different types of ink were used: (a) as seen by the eye; (b) photographed with infra-red film.



using panchromatic film, infra-red film, and appropriate filters are suggested for their possibilities (Fig. 226b). If the pigment of the original writing differs in color or opacity to infra-red rays from the pigment used to obliterate the writing, photographic methods will restore the original writing (Fig. 227).

Ultraviolet light also has been found helpful in deciphering deleted writing. The success of this method depends upon the pigments differing in their properties of fluorescence in ultraviolet light.

In other cases where a pigment different from the pigment of the original writing was used for the deletion, it may be possible to use a solvent that will differentially remove the pigment employed to cover the writing. For example an inscription made with a rubber stamp may be crossed out with a blue crayon. Acetone will be found suitable as a solvent since the crayon is soluble and rubber stamp ink is insoluble (Fig. 226c).

If a suitable solvent is not known, it is possible to make a few preliminary tests on pigments similar to those involved in the obliteration. The object is to find some solvent which will remove the covering pigment and leave the original writing undisturbed. A wad of cotton is moistened with the solvent and then cautiously rubbed over a small section of the obliterated area. If the top pigment is removed and the underwriting left undisturbed, this solvent may be used to remove the remaining objectionable pigment. The solvents to be tried include the following: water; alcohol; acetone; benzine (petroleum ether), carbon tetrachloride, or rectified turpentine; benzene, toluene, or xylene; butyl carbitol; amyl acetate; morpholine ( $C_4H_9ON$ ).

When paper, cardboard, or similar materials have been pasted over the writing, dry carbon tetrachloride or benzene rubbed on the reverse side makes the paper translucent for a few moments. A photograph may then be made of the original writing, if the lighting and camera are arranged so that an exposure of less than one second is required. The evaporation of the carbon tetrachloride requires a somewhat longer time so that no difficulty is experienced on this account. Since the document is photographed from the back, the negative should be reversed in printing.

## EXERCISES

1. Obtain a rubber, ink, and scratch knife type of eraser. Use each on different samples of writing. The erasing should be done as carefully as possible, so as to minimize abrasion. Examine the results for the presence of erasures. Is it possible to erase any writing mechanically without its being detected?

Using ink and several commercial eradicators, repeat the exercise. Perform the various chemical tests described in this chapter, to determine if traces of the eradicator may be detected in this manner.

Repeat the above exercise using a 100 per cent rag content bond paper as well as cheaper grades of bond and sulfite pulp paper. Does the type of paper influence the results obtained?

2. Write your name once with pencil and twice with ink. Erase the pencil and one ink signature with some mechanical eraser; eradicate the other ink signature with ink



eradicator. Try to restore the original writing by physical and chemical methods. Repeat the ink experiment, using ink writing that is several years old. What conclusions may be drawn about the efficacy of these methods? Is it easier to restore pencil or ink erasures which were made mechanically?

3. Obtain several different types of writing materials, each presumably made with a different type of pigment. Cross out the writing made with one kind of pigment by using another writing instrument filled with a different pigment. Prepare several such samples. Select the method (optical, photographic, or chemical solvent) which seems to be the most useful and try to decipher or restore the original writing.

Paste a 4 by 5 file card or several thicknesses of paper over some ink writing. Saturate the reverse side with dry carbon tetrachloride and photograph the original writing. Print the negative in the manner described in the text. Can the original writing now be read in the finished print?

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# CHAPTER 36

## THE EXAMINATION OF DOCUMENTS FOR INVISIBLE WRITINGS

### 1. GENERAL

Questioned documents are sometimes submitted to the laboratory with a request that an examination be made for suspected secret writing. Such cases may arise from an attempt by prisoners of war to communicate surreptitiously with sympathizers or enemy agents, or from criminals in penitentiaries who wish to convey a message requiring concealment from the authorities to friends on the outside. Other instances where invisible writing may be resorted to are communications among criminal gangs, members of secret societies, or subversive political groups. In wartime, espionage information may be communicated from one agent to another in this manner. Generally, when criminals are passing invisible messages it is a simple matter to detect them; when espionage agents are using invisible ink for sending important messages, its detection and development may be quite difficult. In the case of prisoners, natural substances or body secretions, which are readily available, are usually employed. Where a well-developed plan exists, common articles such as toothpaste, soap, medicine, perfume, etc., may be used to send or carry substances to be used as an invisible ink, which in these cases is frequently a relatively uncommon chemical. Another method which has been employed to send secret ink is to soak articles of clothing such as socks, neckties, etc., in a solution of the substance and allow them to dry. The ink is regenerated when needed by wetting the article with the proper solvent, usually water. The substance used for invisible writing is often referred to as a *sympathetic ink*.

Since the materials which are used in secret writings are chemical in nature, it is to the chemist that we must look for assistance. Indeed, the method of detection will consist essentially of well-known reactions carried out on paper, rather than in a test tube.

The initial step in the investigation is to mark the document for identification and photograph it in order to have a record of its original state for court



presentation. The identification mark should be placed in an unimportant part, of the document, preferably on the reverse side.

Frequently, the suspected document has been intercepted in transit, and it is expedient to conceal the traces of an examination from the intended recipient. Hence, a physical examination should be made first, since traces of such treatment are difficult to detect. Following negative results in the physical examination, one must resort to chemical methods. Various processes involved in both the physical and chemical examinations will be discussed below. When secret writings are developed as a result of these examinations, they should be immediately photographed.

Before proceeding it is necessary to discuss briefly the method of manufacturing paper, since this is the medium on which the invisible writing is usually found. Paper is essentially cellulose, impregnated or *loaded* with inorganic fillers such as gypsum and clay, to give body and rigidity. In order to increase the suitability of the paper for the satisfactory retention of inks used in writing and printing, a smooth coating or finish is imparted to the surface. This is accomplished by a process called *calendering*, which consists of pressing between hot rollers onto the surface of the paper a sizing material such as gelatin, casein, or rosin and alum. These substances are soluble in varying amounts in water, alcohol, and other liquids. Thus, mere application of a liquid to the paper surface destroys the gloss, at least partially, by dissolving the sizing material. These alterations of the surface by the invisible writing provide a point for attack and permit a profitable use of physical methods for detecting and developing the writing.

As there is no well-defined approach to the method of development of invisible writing, the following discussion will indicate a systematic method of examination insofar as it is possible.

## PHYSICAL METHODS

### 2. EXAMINATION BY VISIBLE LIGHT

The document is examined by reflected and transmitted light, the source of which may be the sun, electric bulb, or carbon arc. The examination is first made with reflected light of great intensity. Gradually, the intensity of illumination is decreased until it is very subdued. Particular attention must be paid to subdued light falling obliquely on the document, for here the dull condition of the surface, resulting from the removal of the sizing by the solvent action of the secret ink, is detected against the untouched surrounding portion, which retains its glossy appearance. When the document is examined by transmitted light, any area which appears abnormally opaque or translucent should be carefully scrutinized for evidence of tampering to disguise alterations of the surface of the paper. In some cases, the presence of a secret message is detected by this procedure, although the contents cannot always be read. A low-power microscopic examination should also be made.



### 3. EXAMINATION BY ULTRAVIOLET RADIATIONS

Sometimes compounds (both organic and inorganic) which fluoresce are employed in secret writing and they are readily detected by merely exposing the document to invisible ultraviolet light in a darkroom (Fig. 228).

April 1, 1942  
Inapen, N.Y.

Dear Sis:

Thanks for the letter and the spending money. It sure helps along. It seems like a long time since you were up here and I hope you can take it again with Bill next visiting day.

I'm going to try out for the ball team tomorrow. They have some pretty good players but I'm pretty good too.

The Warden had me in for a talk this morning. He seems all right and fair enough.

Movies tonight and I can go so will cut this short. Show this letter to Joe as I know he'll be interested in how I'm getting on.

Your loving brother,  
*John*

(a)

JOE GET MY CUT FROM  
THE LAST JOB TO MANNY THE  
MOUTHPIECE RIGHT AWAY.  
IF HE CAN'T SPRING ME  
I'LL BLAST OUT AND DON'T  
GET NO IDEAS ABOUT ROSIE.  
*John*  
P.S. NO JOBS TILL I GET OUT.

(b)

Fig. 228. A letter bearing an invisible message: (a) as seen in visible light; (b) in ultraviolet radiation.

### 4. EXAMINATION BY INFRA-RED RADIATIONS

Although no method is available by which the infra-red characteristics of a substance used as a sympathetic ink can be determined other than by photographing the document with infra-red film, it is advisable not to overlook this possibility. It is hoped that the ink is opaque to the passage of the infra-red rays whereas the paper should be, and usually is to some degree, transparent. Attention is called to use of oblique illumination as well as the ordinary method of illuminating the document through the back with photofloods when photographing it with transmitted light. Frequently, oblique lighting will reveal characteristics which the usual method of lighting fails to reveal. It should be mentioned that infra-red photography has been used successfully in the development of secret writing contained in old diplomatic dispatches.

### 5. LOW-VOLTAGE X-RAYS

If an inorganic salt, containing a heavy metal such as lead, barium, tungsten, etc., was used as the sympathetic ink it may be possible to detect its presence by passing low-voltage x-rays through the document (see Chap. 22).



In those cases where a piece of paper has been pasted or glued over another, such as on picture postcards or (paper) box covers, soft x-rays may sometimes be useful in determining if a message has been inscribed on one of the inner surfaces.

## 6. GEIGER COUNTERS

The properties of radioactive materials and their use in labeling inks are described in Chapter 28. The appropriation of these principles as a means of secret writing is almost too obvious to require comment. Included then, as part of the examination for invisible messages should be an inspection of the paper by means of a Geiger counter. Activation of the counter indicates that radioactive material is present on the document. Further inspection by *screening* words or individual letters in the words on the document is necessary if the contents of the message are to be learned.

## 7. IODINE VAPORS

The document is next placed in a fuming chamber (such as that which is used for the development of latent fingerprints), and some iodine is sublimed (see Fig. 229). If starch or certain other materials (usually organic) were employed in the invisible writing, they will be developed by this method. If one wishes, any writing made legible by iodine may be eradicated with a 3 per cent solution of sodium thiosulfate (hypo). The document may be somewhat restored to its original condition by pressing and reglossing. Sulfur dioxide fumes will also decolorize the iodine by reducing it, but the paper may show signs of having been tampered with because of the bleaching action of the sulfur dioxide.

If the sender of the secret message has steamed the paper after using the sympathetic ink, iodine fumes are not likely to develop the writing.

## 8. HEAT

There are many compounds which decompose when heated. Usually, these are organic materials. However, there are some inorganic substances which behave in a similar manner. For example, hydrated cobaltous chloride is pink (colorless in dilute solution), but when heated it loses its water of hydration and becomes blue. The following may be mentioned as examples of organic substances which can be detected through this method: milk, lemon juice, starch, saliva, urine, and sugar.

To apply heat, a drying oven may be used although a hot iron pressed against the document is perhaps more convenient, and permits the examiner to control the process better. Another method is to place the document between the plates of an electrically heated photographic mounting press. The document must be kept under observation throughout the time the heat is being applied. Documents containing inflammable material such as celluloid covering should not be heated unless it is possible to remove the inflammable substance. In general, the method is of limited value in the investigation of documents for invisible writing.



## 9. COLORED POWDERS

When the smooth glossy surface is removed by the solvent action of the sympathetic ink on the sizing compounds, the undersurface material is exposed. This is rougher in texture than the finished writing surface, so that, if a finely divided colored powder is dusted or brushed on the paper (as one dusts fingerprints), it will be mechanically retained where the rougher surfaces exist. In this manner it is sometimes possible to develop invisible writing. In the selection of the finely divided powder, care should be exercised in the choice of color. Obviously, the powder chosen should be one which will provide sufficient contrast with the paper. Generally, the same powders used in developing fingerprints are suitable for this work also.

Powders are of doubtful usefulness, since iodine vapor or the iodine-iodide solution described in Chapter 37 will usually develop any writing that powders will develop. Furthermore, development of invisible writing by powder is more or less permanent so that in cases where the document is to be forwarded to the intended recipient its use is precluded. The powder method is mentioned mainly because it is of historical significance; it is one of the earliest methods and was in use for several centuries.

## 10. COLORED SOLUTIONS

A procedure similar to the use of colored powders is the employment of colored solutions (diluted inks, or diluted dye solutions), to develop invisible writing. In this case, the liquid is swabbed on with cotton or, if necessary, the whole document may be immersed in the colored bath. Again, the idea underlying this procedure is the selective absorption of the developing agent at those places where the sizing has been attacked. After the colored solution is applied, the document is washed under running water. An alcoholic solution of a dye may be used when any ordinary writing on the document tends to run or be dissolved in water.

In addition to the disadvantages described in the next section where water is used as a developing agent, writing made legible by this method is more or less permanent. The undesirability of this was mentioned in the preceding section. Colored solutions then, as developing agents, are mainly of historical interest and of little practical value today.

## 11. WATER AS A DEVELOPING AGENT

Castor oil and certain other oils dissolved in suitable organic solvents to form dilute solutions have been used as sympathetic inks. Similarly, simple inorganic acids such as hydrochloric and nitric, and organic acids such as acetic and oxalic, have been employed in dilute solution as secret inks. These may be developed by merely wetting the document with water and examining it with transmitted light. In these cases the places containing the sympathetic ink will become more translucent and may be read without difficulty.



There are several disadvantages in using water as a developing agent:

If the document contains writing made with ordinary ink it will usually run.

If the invisible writing is not developed by this means and the sympathetic ink used is soluble in water, subsequent methods are doomed to failure.

If the document is to be passed on to the intended recipient, the paper must be pressed and reglossed.

For these reasons water is of limited usefulness. Usually inks which are developable with water will also be detected by one of the other physical methods above or by the iodine-iodide solution mentioned in the next section.

## 12. CHEMICAL EXAMINATIONS

Chemical detection of invisible writing is more difficult because of the large number of chemicals which can be employed, and the fortuitous possibility of

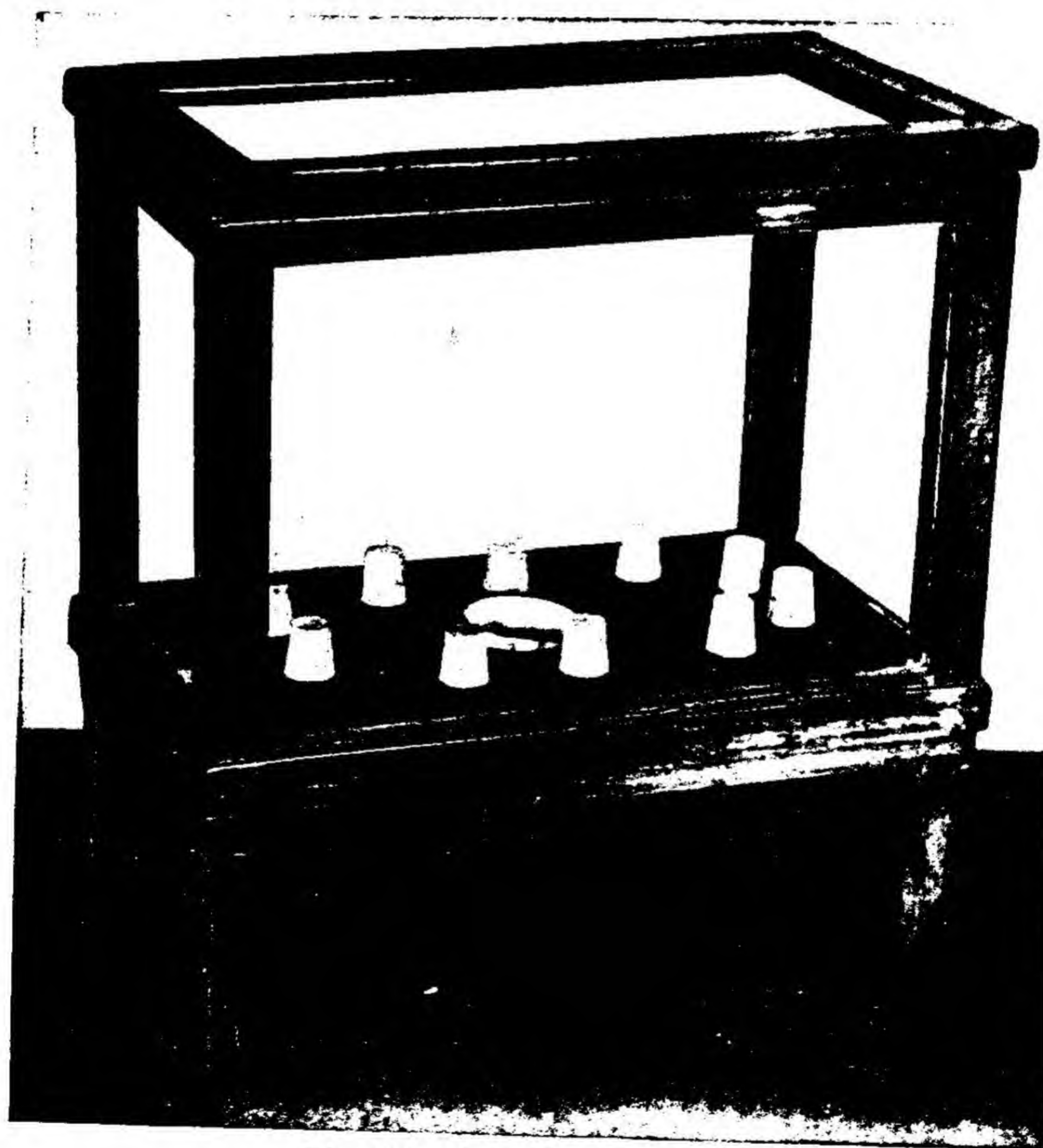


Fig. 229. A fuming chamber.

selecting the specific reagent for developing the compound used as the sympathetic ink. Frequently, however, if the paper is exposed to hydrogen sulfide fumes or, better, ammonium sulfide fumes in a fuming chamber (Fig. 229), it will be possible to detect many inorganic substances through the production of an insoluble colored, metallic sulfide. If this method fails to develop any secret



writing, the services of a chemist are required. When the amount of writing is small, the difficulties of the task are increased and the chances of success correspondingly reduced.

Mention will be made below of a few other reactions which may be of assistance in chemically detecting secret writings. However, the method selected will depend upon any additional information which the investigator can obtain; namely, the background of the person suspected, the materials available to him, the purpose of the disguised writing, the person to whom it is being sent, the facilities of that person for developing the writing.

The iodine-iodide solution described in Chapter 37 may be used as a last resort when nothing is known of the type of sympathetic ink employed and where all previous efforts — physical and chemical (vapors) — have failed to develop any invisible writing on the document.

If an acid or base indicator has been employed, fuming with ammonia (base indicator) and glacial acetic acid (acid indicator) will develop the indicator employed.

Potassium ferricyanide and in some cases potassium ferrocyanide may be used as bathing reagents to develop copper, iron, zinc, and silver compounds. If potassium thiocyanate is acidified with dilute hydrochloric acid and the gas developed (thiocyanic acid,  $\text{HSCN}$ ) directed against the paper it will turn any ferric compounds present to a red color. An apparatus convenient for preparing thiocyanic acid is shown in Fig. 230.

If ordinary table salt has been employed in the invisible writing, it can be developed with silver nitrate using

the method by which latent fingerprints are developed.

Mention should also be made of diazo papers. These are coated with a light sensitive material (a diazonium salt) and, using the proper developer, it is possible to bring out any writing which might have been placed thereon. The developer consists of a coupling reagent such as a dilute acid solution of an aromatic amine (*m*-phenylenediamine). The coupling reagent reacts with the diazonium salt to form an azo dye.

When tests are being made to determine the correct chemical needed to develop the sympathetic ink, all gaseous developing reagents (hydrogen sulfide,

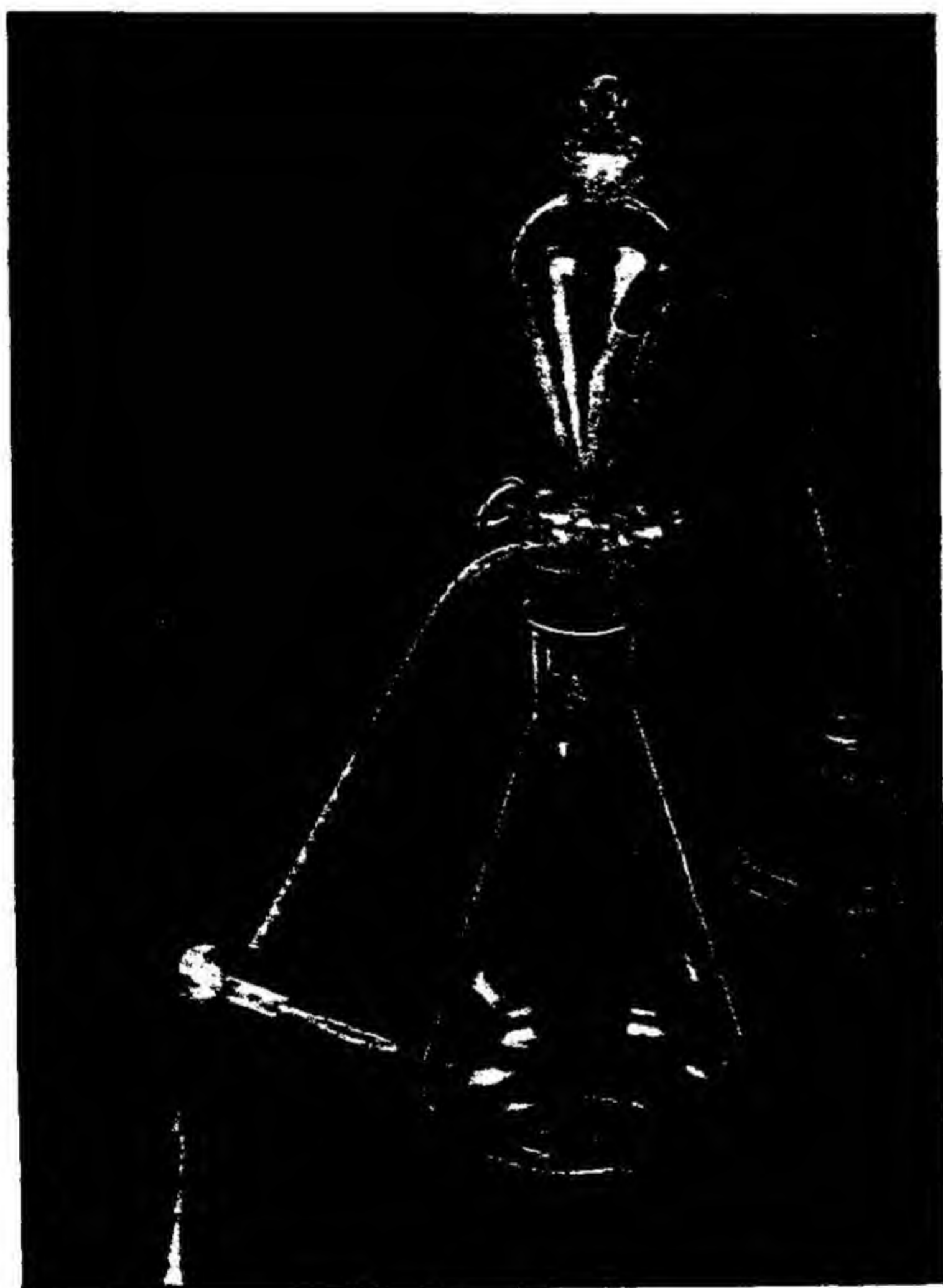


Fig. 230. Apparatus for preparing thiocyanic acid, hydrogen sulfide, and other gases used in fuming documents.



ammonium sulfide, thiocyanic acid, etc.) should be employed first. Whenever possible, liquid developing reagents should be volatilized in a fuming chamber by carefully heating the vessel containing the liquid. Finally, solutions are applied by rubbing diagonally across the document a swab of cotton moistened with the developer. Solutions are not to be used indiscriminately however. They should not be used in such a way as to preclude the use of other solutions (i.e., the document should not be bathed) or worse, to destroy completely the possibility of further tests.

### 13. PRACTICAL APPLICATIONS IN ANONYMOUS LETTERS

Some practical use for invisible writing materials may be found in marking postage stamps which are to be sold to a limited number of known persons (as in an office), one of whom is suspected of being the author of annoying anonymous (poison pen) letters. The stamps may be marked across the face with a number written with some invisible characteristic fluorescent compound (see Chap. 28). After the stamp is sold the name of the person who made the purchase is entered next to the number corresponding to that on the stamp. When the next anonymous letter is received, the stamp is examined under ultraviolet light. The convenience of a ready supply of stamps usually results in a person's buying his stamps from this source, rather than taking the trouble of going to the post office for such purchases. Quite frequently then, the identity of the person in the office who is responsible for the letters will be revealed in this manner.

### EXERCISES

A round tip, smooth writing pen or wooden tooth pick should be employed for writing which is intended to simulate secret writing. If an ordinary sharp, pointed pen is used, it is likely to dig into the paper and thereby simplify the task of discerning the writing. Thus, a clever individual who wishes to hide his message would be unlikely to use such a pen.

The student should write his name on a piece of bond paper with each solution listed below. Five such pages should be prepared, using different types of paper. The solutions used should be diluted with water, and comprise the following:

- Milk (diluted until colorless)
- Urine (diluted until colorless)
- Regular blue-black ink (diluted until colorless)
- Aqueous solution of cobaltous chloride (diluted until colorless)
- Aqueous solution of ferric sulfate (diluted until colorless)
- Alcoholic solution of eosin (diluted until colorless)
- Oxalic or acetic acid (a dilute solution)
- Hydrochloric acid (a dilute solution)

After allowing these solutions to dry thoroughly they should be examined as indicated. Those substances detected by the physical examination should be noted as well as those which are detected only by the chemical examination. Did any substance go undetected? Can you think of any substance which would be undetectable? If so, try it.



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# CHAPTER 37

## MISCELLANEOUS DOCUMENT PROBLEMS

### 1. INDENTED WRITING

#### Under Sheets in Pads or Checkbooks

Whenever writing is made on a leaf or sheet of a pad, book, or sheaf of papers, not only is the topmost sheet affected but the under sheets, sometimes as far down as the fifth or sixth, also receive impressions from which it is possible to determine the text of the original writing. These impressions are designated by the term *indented writing*. Cases involving indented writing are of common occurrence in the police laboratory. For example, a bookmaker's pad may be found with the top sheet removed. It then becomes necessary to determine the original text from the impressions on the pad. These impressions will frequently be the names of horses followed by the amount bet and the manner in which the bet is laid. For instance, "Flagpole 0-1-0" means that one dollar is bet on Flagpole for "place." The amount for which a previous check was drawn may be significant in a case and may sometimes be determined from the checkbook by the indentations. Several methods may be used to make indented writings legible.

#### Side Lighting

The indentations in the paper can be seen in relief by illuminating the paper with the line of light almost parallel to the plane of the paper. A narrow beam of light can be obtained by means of a mask over the illuminant. The depressions in the paper will appear as shadows on the untouched surface and writing will be thus outlined. Photographs should be made with the pad lighted in this manner (Fig. 231). In photographing, two negatives should be made — one using a long-scale film such as a portrait film and one with process film. The long-scale film is necessary because of the great range of tones which result from this type of lighting. The process film is used to emphasize important details which are difficult to read in the other film.

#### Indented Writing Solution

The force of the writing instrument on the surface of the paper causes a deformation of the fiber structure of the paper beneath. If an iodine solution,



the composition of which is indicated below, is dabbed with cotton on certain kinds of paper, the indented writing becomes immediately visible and can then



Fig. 231. Indented writing photographed with oblique lighting. The writing is a record of "policy" bets.

be photographed. If the paper is dabbed with a 1 per cent solution of hypo ( $\text{Na}_2\text{S}_2\text{O}_3$ ), traces of the first solution disappear and the paper is restored to its original condition. This method may also be used for detecting alterations such as erasures or removal of writing on checks. It must be remembered, however, that the method is not applicable to all kinds of paper. The excellent results obtainable in many cases justify the experiment.

The composition of a solution suitable for developing indented writing is as follows:

Water	8 ml
Potassium iodide	4 g
Iodine	1 g
Glycerin	20 ml

Dissolve the potassium iodide in the water, add the iodine and stir until the crystals dissolve. Add the

glycerin and mix well until a homogeneous solution is obtained.

### Iodine Fuming

The alteration of the fiber structure mentioned above is the basis for another method of rendering indented writing visible. Iodine crystals are heated in a hood. When fumes are seen rising above the crucible, the paper is suspended over the fumes for a short time. The paper is darkened by the fumes to a greater degree in the lines of the writing, and in this way the text becomes visible. The paper should be withdrawn before it darkens excessively and contrast is lost. A photograph should be made immediately because the writing is fugitive and will disappear in time.

### Indentations on Reverse Side

In cases of obliterations where the writing on a sheet of paper has been obscured by overwriting with ink, crayon, or other means, it is sometimes possible to discern the nature of the writing by examining the reverse side. If the original writing or typewriting was made with heavy strokes, the paper will have been pushed out on the reverse side in the pattern of the writing. Photography with side lighting as described above should be used in these cases.



## 2. WRITING ON CARBON PAPER

One of the traces that is sometimes overlooked by the criminal is the carbon paper which was used to make a duplicate copy of some message or record involved in an illegal transaction. Frequently it is possible to decipher the complete original text by a careful examination of the carbon. If, however, the carbon has been used too often, the writing will be overlapped so much that it is scarcely legible. It will be found that the text of the carbon is more easily studied in a properly managed photograph. Examination of the carbon itself, however, under varied lighting conditions, should supplement the study of the photograph. The photograph is, of course, invaluable for the purposes of court demonstration.

The method used to photograph the writing on a sheet of carbon paper depends upon the extent to which the sheet has been used and the pressure applied with the writing instrument. A classification into two cases will be sufficient to illustrate the techniques.

### Carbon Used Only Once

When the carbon has been only lightly used and no overwriting is present, the only change on the carbon side of the paper is a removal of the carbon in the path of the writing. By carefully illuminating the carbon

face from the side and photographing with process film, a clear reproduction of the writing can be made. Fig. 232 is an example of such a photograph.

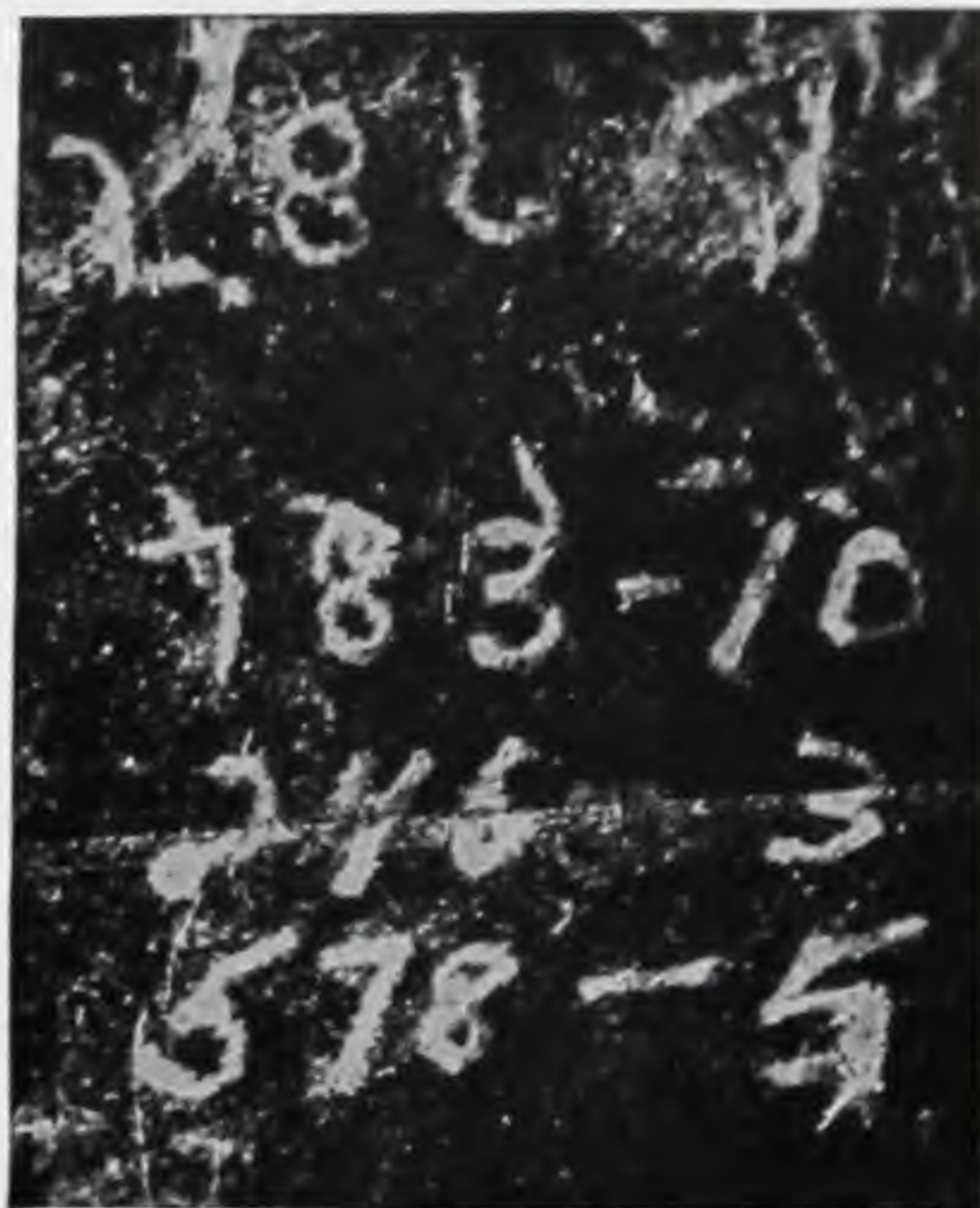


Fig. 232. Writing on carbon paper photographed with oblique lighting.

### Worn Carbon Paper

When carbon has been used a great deal, the paper becomes thin, translucent, and even perforated from the writing. Sometimes a satisfactory reproduction can be made by using the carbon paper as a negative and printing it directly on photographic paper. The carbon is placed on the printer as though it were a negative (Fig. 233).

A much superior reproduction can often be made, however, by means of a photograph. The paper should be suspended in a frame and illuminated directly through the back of the paper. From the point of view of the camera lens the light is shining through the paper. Since the paper is blue, the transmitted light is also blue except where the paper is badly worn. In the worn areas white



light shows through. By photographing through a red filter with a panchromatic (process pan) film, an excellent reproduction with greatly increased contrast can be made.

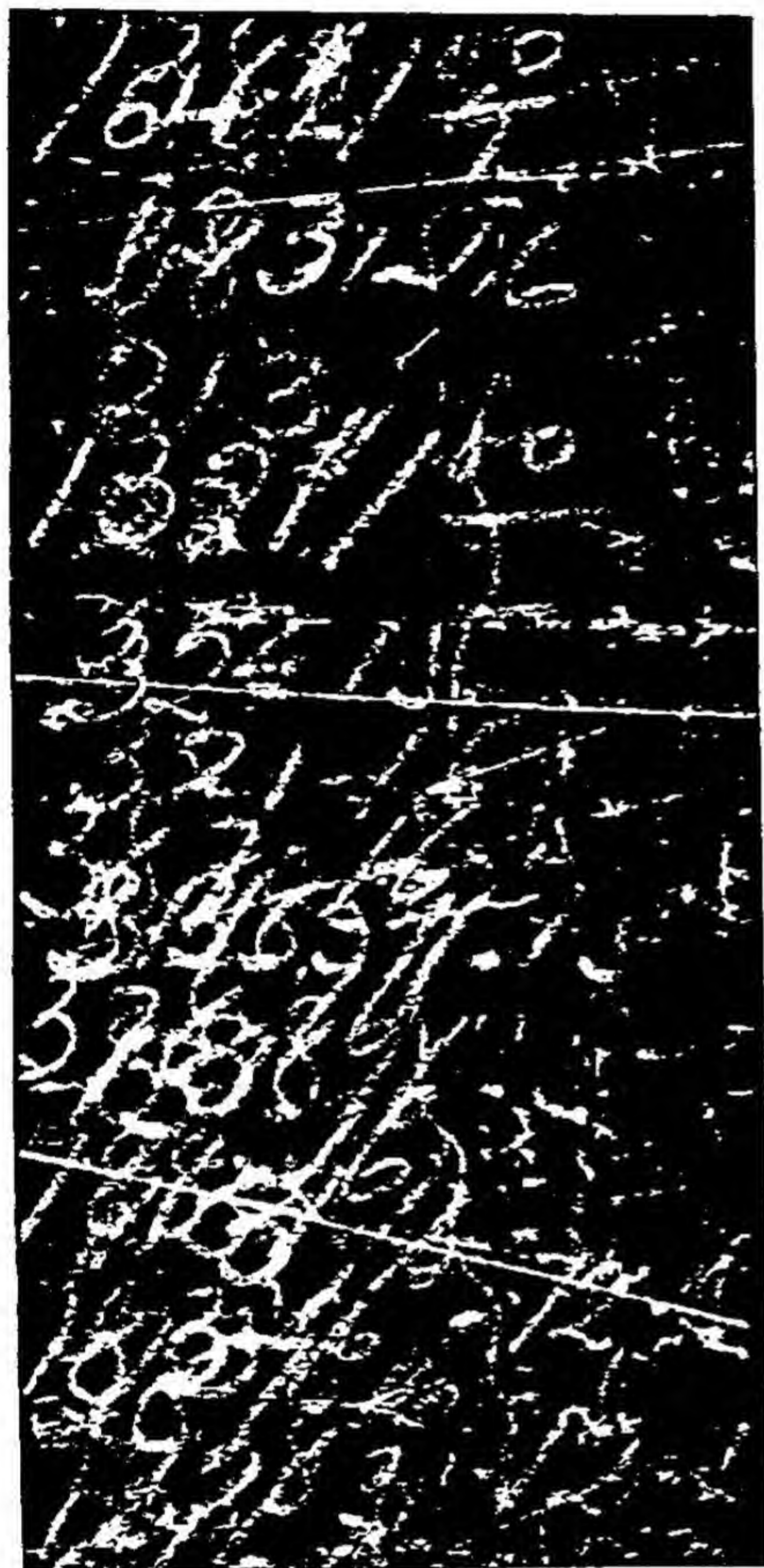


Fig. 233. Writing on carbon paper. The carbon paper was used as a negative and printed directly on photographic paper.

### 3. CHARRED DOCUMENTS

Documents which have accidentally been burned in a fire or which have been purposely destroyed in this manner may sometimes be deciphered in the laboratory. The techniques to be described by no means set a limit to the resources of the criminalistician when presented with this problem. The conditions to which burning may reduce documents are so varied that the present discussion can lay no claim to comprehensiveness. The degree of carbonization and the variety of paper and ink militate against generalities.

#### The Handling and Preparation of Burned Paper

Usually burned paper does not remain intact but breaks into fragments, the edges of which frequently are curled. These pieces are quite brittle and great difficulty is encountered in setting the fragments in one plane so that they may be photographed. Where the charring is not severe the document may be mounted on glass with small dabs of an adhesive. A 2 per cent solution of celluloid or collodion in amyl acetate is suitable for this purpose. When the charred

piece has been thoroughly immersed in this solution, it is possible to smooth out the curls and twists in the charred piece by means of the fingers or a camel-hair brush. The adhesive is removable, without damage to the charred document, by acetone or similar organic solvent.

In severe charring where brittleness is encountered, the paper should be placed first in a chamber in which there is an exposed, broad, shallow tray of water until, by absorption of moisture, it has become more flexible. It can then be placed carefully between glass plates and as a record of its appearance a photograph can be made (Fig. 234a). Under the best conditions, this problem presents a difficult and a tedious task. Great patience and considerable practice is necessary before any degree of adeptness is acquired in the ability to uncurl a burnt piece of paper.<sup>1,2</sup>



### Process Film

Since in many cases some of the writing is visible, a photograph with process film should first be made to increase the contrast and to record that writing which may be seen (Fig. 234b). Although little space is given here to this method, it will be found that ordinary photography is frequently one of the best means of rendering charred documents legible.



(a)



(b)



(c)



(d)

Fig. 234. A charred document photographed: (a) normally; (b) with process film; (c) with process film and oblique lighting; (d) with infra-red film.

### Filters

The colors of the paper and ink may be so related that a successful photograph can be made by means of an appropriate filter. The document should be examined visually with a series of filters until a choice is made. Process panchromatic film should be used.<sup>3</sup>

### Oblique Lighting

The reflective qualities of the inked area of the paper may be greater than that of the blank area, i.e., the critical angles may be different. In such cases, oblique lighting will yield the desired contrast in a photograph. The lamp should be carefully manipulated until the writing becomes light while the background is dark, or vice versa. Process film should be used (Fig. 234c).



If the degree to which the light is polarized differs in the inked and paper areas, a polarizing screen over the camera lens will be of assistance in deciphering the writing.<sup>4</sup>

### **Infra-Red Photography**

Depending on the nature of the ink or other writing material, the composition of the paper and the degree of charring which the paper has suffered, an infra-red photograph may sometimes aid in deciphering the writing.<sup>5</sup> If there are many fragments, a 35 mm film camera should be used. Several exposures may be necessary, depending upon the degree of charring, to produce the proper contrast (Fig. 234d).

### **Exposure of Photographic Emulsions by Contact with Charred Paper**

It is possible to achieve contrast in a photographic plate by other means than the use of light. A chemical reaction sometimes takes place when the charred document is merely left in contact with a sensitized emulsion.<sup>6</sup> Two photographic plates are used. The charred document is placed between the emulsion sides of the plates. Plates of the highest emulsion speed obtainable should be used. An orthochromatic emulsion is most suitable since it permits the use of a red light in the darkroom. The plates are then pressed together in a frame or by means of a weight. The document and plates are left in contact for at least two weeks. The plates are then developed, fixed, and washed.

The explanation of this phenomenon must include two cases: First, the reducing agent is present in the paper and not in the ink; second, the reducing agent is present in the ink and not in the paper. The variables of ink and paper determine the success in any case.

### **Silver Nitrate Method**

A method similar to the photographic emulsion contact method is that described by Murray.<sup>7</sup> It is claimed that this method is of value in those cases where the paper has been incinerated at a high temperature in the virtual absence of air, such as might happen in a small safe, filing cabinet, or safety box. Briefly, the procedure may be described as follows:

The carbonized sheet is placed on a piece of glass. This is set into a glass or enamel tray and a 5 per cent aqueous solution of silver nitrate is carefully poured into the tray. A second glass plate, supported by glass rods or rubber stoppers placed on the first glass plate, is set over the paper to protect it from damage. The writing appears as a black image against a gray background. It may frequently be photographed *in situ*. To preserve the results, the document is washed several times with distilled water and dried.

The success of the method depends upon a reducing agent being present in the ink, so that the silver ions can be reduced to free silver. Because direct sunlight decomposes silver nitrate, it is necessary that the room in which the process is carried out be illuminated with electric light or subdued, indirect daylight.



### Chloral Hydrate Method

A new and simple method in which chloral hydrate ( $\text{CCl}_3\text{CHO} \cdot \text{H}_2\text{O}$ ) is employed to develop the printing or writing on charred documents has been suggested by Taylor and Walls.\* No explanation has been devised which accounts for the action of the chloral hydrate.

The procedure is as follows:

A solution containing 25 g of chloral hydrate in 125 ml of ethyl alcohol is prepared. The burnt paper is immersed in this reagent, taken out immediately, and dried at 60 C. This procedure is repeated several times until a mass of chloral hydrate crystals forms on the surface of the document. A final immersion is then made in a similar solution, to which 13 ml of glycerin have been added. The document is again dried at 60 C. Both sides of the paper are examined. Process film is used to photograph any writing or printing which develops.

## 4. CONTACT WRITING

Occasionally it is necessary to process a piece of blank paper for traces of ink which it may contain because of previous contact with some writing. For example, a page may have been torn from a business record or a personal diary, and for the purpose of an investigation, it may be important to learn what information was contained on the missing page. Again, an envelope in which a letter was sent may contain traces of the ink writing with which it came in contact. These invisible traces, which are nothing more or less than the constituents of the ink, are more likely to be present if the writing was not allowed to dry thoroughly before it was placed in contact with the paper to be processed. The present chapter describes the techniques and chemistry of the methods used to develop the traces so that they become legible and may be photographed.

The following procedure has been recommended:

"The surface of the paper is treated in the darkroom by red light with a solution composed of 5 grams of silver nitrate, 1 gram of citric acid and 0.5 gram of tartaric acid and three drops of nitric acid in 100 grams of distilled water. The writing is developed in ordinary daylight and fixed with ordinary fixation. Since the process of fixation weakens the intensity of the letters it is advisable to photograph the writing first."<sup>9\*</sup>

The chemistry of this method may be interpreted as an oxidation-reduction reaction:



The ferrous ion of the ink is oxidized by the silver nitrate to ferric ion, and free silver is deposited. However, this reaction takes place only in boiling solution.<sup>10</sup> Therefore, it is necessary to add citric and tartaric acids to the reagent in order to form complex ions with the ferric ions which are formed; the system also absorbs energy upon exposure to visible or ultraviolet light, thereby permitting the reaction to proceed at room temperature.

This may be an oversimplification of the reaction. It has been claimed that

\* From *Modern Criminal Investigation*, rev. ed., by Söderman and O'Connell, copyrighted 1935, 1940, 1945 by the Funk and Wagnalls Company.



it is actually much more complex since a gray precipitate which is thought to be  $\text{Ag}_2\text{O}$ , silver suboxide, or a mixture of some organic substance with finely divided silver is also formed.<sup>11</sup>

Since we know from Rhodes' work (Chap. 34) that a negligible amount of ferrous ion is present in ink writing after one month, this method will not be very useful after this time. Other methods are available if the elapsed time is greater than thirty days. These are discussed below.

### Chloride and Sulfate Pictures

In Chapter 34 it was learned that hydrochloric acid (and sometimes sulfuric acid) is added to nutgall and logwood inks. Sulfate ions are present in nutgall ink because of the ferrous sulfate which is a principal constituent. In other inks, sulfates are not present in any quantity unless sulfuric acid was added. In the procedure to be described these inorganic anions are converted into colored compounds which form an outline of the original writing. This developed writing is called a *chloride or sulfate picture*.

The principle upon which chloride or sulfate methods are based is their conversion into insoluble, colorless, silver or lead salts respectively. These are then reduced to the free metal or converted into colored compounds to form the chloride or sulfate picture.

In addition to their use in contact writing cases, chloride and sulfate pictures may be of value in other independent lines of investigation; briefly these are:

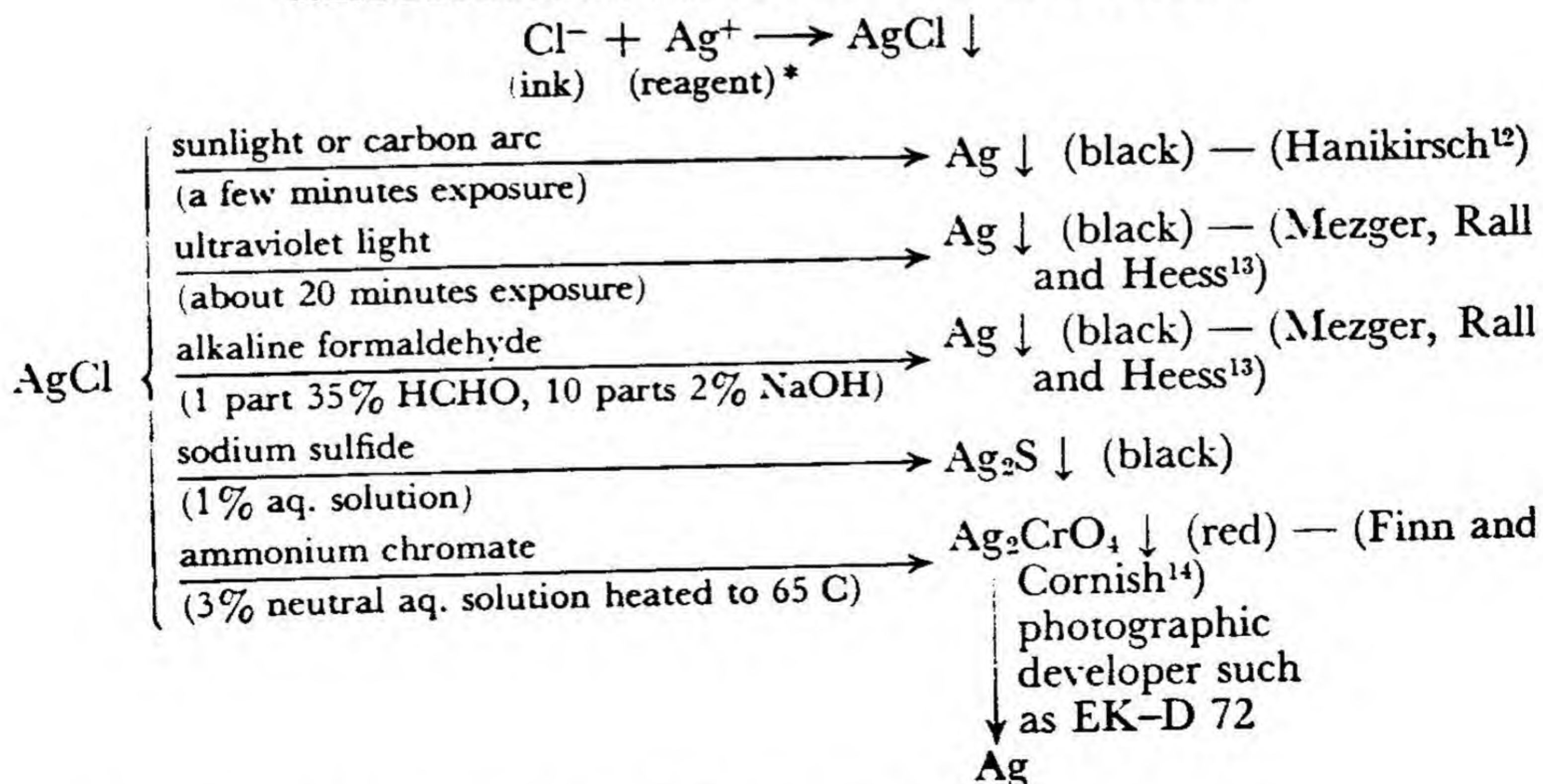
Development of mechanically erased writing

Estimation of the relative ages of writings made with certain types of ink

Comparison or differentiation of two ink writings alleged to be the same

The following equations correlate the various procedures that have been proposed in connection with these independent problems:

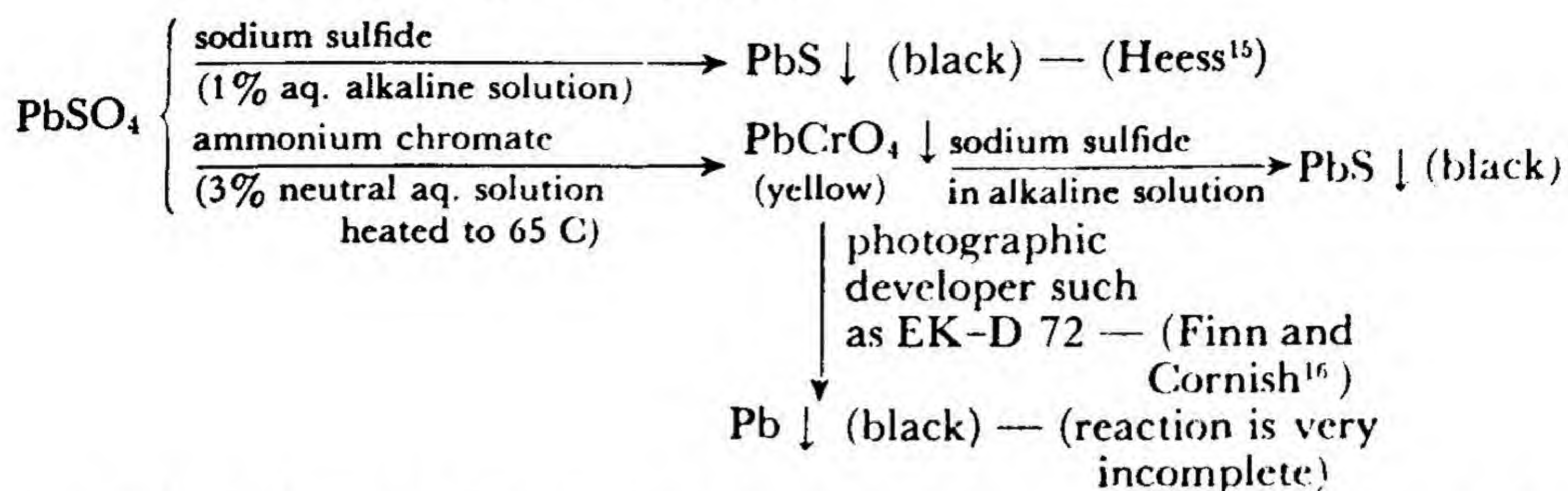
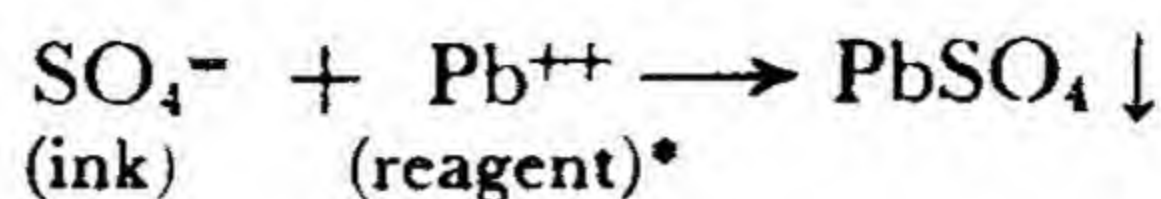
### REACTIONS INVOLVING CHLORIDE IONS



\* About a 4% aqueous solution of silver nitrate.



## REACTIONS INVOLVING SULFATE IONS



\* A 2% lead acetate solution, a 4% lead nitrate solution or a 5% lead perchlorate solution in 5% perchloric acid have been proposed.

## Discussion of Methods

It should now be apparent that the procedures vary only in the choice of method of development of the colorless silver chloride or lead sulfate. When the tests are to be conducted on the ink line itself, as is the case for age and differentiation† procedures, it is necessary to destroy the color of that portion of the ink line where the tests are to be performed, otherwise the picture would be masked by the color of the ink itself.

Various oxidizing agents have been suggested to decolorize the ink, but in general a 1 per cent solution of potassium permanganate acidified with concentrated nitric acid is used. Excess permanganate is removed with a 10 per cent solution of hydrazinium nitrate. This is also referred to as hydrazine nitrate ( $\text{NH}_2\text{NH}_2\text{HNO}_3$ ).

Obviously, this oxidation is unnecessary when contact writing or erasures are to be developed, for if any color were present it would only contribute to the legibility which it is hoped will be achieved through the development of a picture.

The following methods are divided for convenience into two procedures: the first requires no oxidizing reagent; the second includes the use of such a compound to destroy the color of the ink line.

## PROCEDURE IN CONTACT WRITING AND ERASURE CASES

A solution containing 5 grams of lead nitrate, 4 grams of silver nitrate, and 0.8 ml of concentrated nitric acid per 100 ml of distilled water is added with a capillary pipette to a small area where the writing is suspected to be. After 3 or 4 minutes, excess liquid is removed with a blotter and the moistened area is washed three times with distilled water. A few drops of a solution containing 5 grams of sodium or ammonium sulfide per 100 ml water are added to the area

† Except in the Finn-Cornish method.



with a capillary pipette. After a few minutes, the excess reagent may be removed and a fresh application of the sulfide reagent made, if necessary. Both chloride and sulfate ions, as a result of this method of processing, will appear black because of formation of silver sulfide or lead sulfide, respectively.

#### *PROCEDURE FOR EXAMINATION IN ESTIMATING AGE OF WRITING OR DIFFERENTIATION OF INKS*

A solution containing 5 grams of lead nitrate, 4 grams of silver nitrate, and 0.8 ml of concentrated nitric acid in 100 ml of distilled water is added with a capillary pipette to a small portion of a line in the writing. After 3 or 4 minutes, excess reagent is removed with a blotter and an oxidizing reagent is added to destroy the coloring matter of the ink itself. A 1 per cent solution of potassium permanganate, slightly acidified with concentrated nitric acid, is used for this purpose, being applied in sufficient quantity (usually 1 or 2 drops) to destroy the coloring matter of the ink. Any excess reagent is removed with a blotter, and a drop or two of a special solution (v.i.) of hydrazinium nitrate is added to the area to destroy excess permanganate. After a minute or less, the reducing agent (hydrazine) is removed with a blotter, and the area is washed with a few drops of distilled water. The water is removed with a blotter after 10 to 20 seconds have elapsed. Two or three washings are sufficient.

The special hydrazinium nitrate solution is prepared as follows: A solution of silver nitrate is precipitated by hydrochloric acid, and a solution of lead nitrate is precipitated by sulfuric acid. The respective precipitates are washed several times with distilled water. The precipitates are transferred to a 100-ml beaker, and 10 ml of distilled water are added; the mixture is heated to boiling, allowed to cool to room temperature, and 1 gram of hydrazinium nitrate is added. The mixture is stirred well for several minutes. It is then transferred to a test tube and allowed to settle. The clear, supernatant liquid is used in the procedure described above.

An alkaline formaldehyde solution (1 part of 35 per cent formaldehyde to 35 parts of 2 per cent sodium hydroxide) is used to develop the latent image of any chlorides that were present. This reagent should be used only on a portion of the treated area, so that a test may also be made for sulfates. If necessary, it is possible to remove the formaldehyde by several washings with distilled water and blotting paper.

A neutral 3 per cent ammonium chromate solution is added to the washed area, and if sulfates are present a yellow color will develop. In iron tannate inks a sulfate, of course, will always be present due to the ferrous sulfate that is used in its compounding. Thus, for certain iron nutgall inks it is possible that both the formaldehyde and chromate reagents will give positive tests.

The information obtained from this preliminary examination will provide the necessary data for the selection of the procedure to be used in the estimation of the age of writing by the sulfate or chloride picture.

In the case of the differentiation of inks, this data studied in conjunction



with that obtained by the method of Finn and Cornish<sup>17</sup> will provide a better basis for rendering an opinion. In the Finn-Cornish method no oxidizing agent is used, so that the colored chromates blend with the original color of the ink to give green, blue, black, red, pink, and orange colors. The above procedure will show whether either or both anions were present.

With respect to the question of age, if the two ink lines are treated in exactly the same way, a comparison of their respective ages may be made in some cases, using the relative intensities of the yellow colors for the sulfates and of the brownish-red colors for the chlorides as the basis for the comparison.

### Cationic Pictures

The sensitivity of certain reagents that are used to detect iron, copper, chromium, and vanadium makes it possible sometimes to develop contact writings when one of these metals is a constituent of the ink involved. The colored compound, which results when the metallic cations react with the test reagent, forms an outline of the original writing and will be referred to hereafter as the *cationic picture*.

If the document under examination contains ink writing also, the ink identification tests outlined in Chapter 34 will assist the examiner to select the cation most likely to be present in the contact writing. Iron nutgall inks obviously would contain iron; logwood inks contain either chromium or copper; certain colored inks contain vanadium. If nothing is known about the ink that may have been used, it is advisable to employ the tests for iron first, followed by the tests for chromium, copper, and vanadium, respectively.

### Iron

In contact writing cases, solutions of ammonium thiocyanate and sodium sulfide are most suitable for developing the cationic picture when an iron gallo-tannate ink was used.

### Chromium

Diphenylcarbazide is an organic reagent capable of detecting amounts of chromium as small as 0.00025 mg.<sup>18</sup>

The following spot test is carried out on a small area selected as being likely to have traces of contact writing:

### PROCEDURE

With a capillary pipette, add to the area one drop of a solution containing 4 grams of sodium hypochlorite and 2 grams of barium chloride in 100 ml of distilled water. After a few seconds add a very small crystal of phenol (the size of a bird seed) and one drop of a 1 per cent diphenylcarbazide solution in alcohol. A red coloration will appear since diphenylcarbazide is an alkaline solution. This color is discharged by adding a few drops of a 10 per cent sulfuric acid solution. A blue-violet color appears if chromate is present, and an outline



of a mirror image of the original writing will be apparent. Any results must be photographed; in making the positive print the negative must be reversed. If no results are obtained, excess reagents are taken up with a blotter. Finally, when the tests for the other cations have been performed, the document should be washed with distilled water to prevent its deterioration or destruction by the reagents used.

These directions vary from those found in Mitchell<sup>19</sup> in that the reaction is carried out in its entirety in alkaline medium since 0.00025 mg of chromium is detectable in this manner, whereas the acidified diphenylcarbazide reagent suggested in Mitchell decreases the sensitivity to 0.0008 mg.

### **Copper**

Diphenylthiocarbazone (dithizone) is an organic reagent capable of detecting amounts of copper as small as 0.001 mg.

The following spot test is carried out on a small area selected as being likely of having traces of contact writing.

#### *PROCEDURE*

A drop of 2 per cent ammonium hydroxide is placed on the area selected; after a few seconds, a drop of dithizone reagent is added. This reagent is prepared by dissolving 10.0 mg of diphenylthiocarbazone in 500 ml of carbon tetrachloride. The green color of the reagent changes to brown if copper is present, and a reversed outline of the original writing will be apparent. Any results must be photographed. In making the positive print the negative must be reversed in order to make the results legible.

### **Vanadium**

A very delicate test for vanadium consists of the oxidation of a vanadate to pervanadic acid ( $\text{HVO}_4$ ). It is said that 0.0025 mg of vanadium in one drop of solution may be detected in this manner.

#### *PROCEDURE*

To the area selected add one drop of a solution containing 12 ml of concentrated nitric acid per 100 ml distilled water. After a minute add 1 drop (avoid excess) of a 1 per cent hydrogen peroxide solution. If vanadium is present a reddish-brown color will develop and a reversed outline of the original writing will be formed.<sup>20</sup> Any results achieved through this reaction must be photographed. To restore legibility to the writing, the negative must be reversed when the contact print is made.

### **EXERCISES**

1. Write five lines on a pad of paper, varying the pressure of the pencil from line to line. Remove the top sheet, photograph the pad, using oblique illumination.
2. Prepare the indented writing solution described in the text. Examine the pad used in exercise 1 under a microscope, noting the appearance of the paper fibers in



region of the indented writing. Brush the indented writing solution on the paper. Study its effect under the microscope. If the fluid does not render the writing visible, experiment with other samples of paper until one is found which reacts properly. If the reaction is favorable with the first sample, experiment until a paper is found which does not react. Again, note the condition of the fibers.

3. Selecting a paper pad which will react favorably with the iodine-iodide solution, write one line quite heavily on the upper surface. Remove the top sheet. Apply the solution to each of the underlying sheets until the solution no longer has an observable effect. Clean all sheets with hypo.

4. Using five different samples of paper, write the same text on each. Expose each to iodine fuming, and note results.

5. Using heavy pressure, write a message on a sheet of paper so that the paper is pushed out on the reverse side. Obscure the writing on the obverse side by writing over with ink or pencil. Photograph by side lighting on the reverse side.

6. Prepare samples of writing on several carbon papers, experimenting by varying the pressures of the writing instrument. Use both typewriter and pencil. Take photographs using the appropriate lighting technique.

7. Use a badly worn carbon, photograph with a red filter as described in the chapter above and also print through the paper itself.

8. Compare the results of exercise 7.

9. (Two test specimens are to be prepared for exercises 9 and 10). (a) Remove a page from an old book or magazine. (b) Using an ordinary sheet of writing paper, inscribe a message in ink and in pencil. Use a different kind of ink on each line of the penned message.

Char the two documents on a hot plate or in an oven. Prepare the documents for a photograph. Examine the documents in oblique light. If oblique lighting is relatively ineffective, photograph the papers using process film. If all the writing is not visible in the photograph — a circumstance depending upon the degree of charring — photograph the documents with an infra-red filter and film.

10. Prepare six sets of documents similar to those in exercise 9, using sheets about 2 in. square, varying the type of paper in each case. Char these documents until they are illegible. Photograph in the infra-red. Now place the papers between the emulsions of two high-speed plates. Allow the papers and plates to remain in firm contact for three weeks. Develop the plates as usual.

11. Prepare four sets of documents similar to those in exercise 9. On two of the sets use the chloral hydrate method of development; on the remaining two sets use the silver nitrate method.

12. Repeat exercises 9, 10, and 11, with this change: instead of charring the documents in an oven or on a hot plate, actually ignite them with a match and allow to burn with no interference.

13. Sign your name in a business ledger or note book with ink. Blot the writing and close the book. After an hour, test the contiguous page for traces of contact writing. Try the sulfate and chloride methods first; lastly try to develop the cationic picture.

Repeat the above, after 24 to 48 hours have elapsed before the book is reopened and the tests made.

14. Repeat exercise 13, without using a blotter. Employ a pen that allows the ink to flow freely. Close the book quickly after the signature has barely dried.



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# **PART H**

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## **OPTICAL METHODS OF ANALYSIS**







# CHAPTER 38

## MICROSCOPY

### 1. THE MICROSCOPE IN POLICE SCIENCE

The acquisition of a good microscope is, without doubt, one of the first important steps in properly equipping a police laboratory. In the hands of a skillful operator the microscope can take the place of a number of other instruments, and, in laboratories where financial necessities rule the selection of instruments, the microscope may in fact be made to serve as spectroscope, refractometer, colorimeter, densitometer, and so forth. The profitable application of this instrument in a laboratory has limitations which lie ordinarily not in the microscope itself but in its user. The microscope is seldom used properly and even more rarely understood in principle.

In the work of the forensic analyst a preliminary microscopic examination of a sample should be a matter of routine. A careful study of the sample under the microscope before application of other methods of analysis will often save considerable time by indicating to the investigator the probable nature of the sample. Although space does not permit a treatment of crystallographic analysis, it should be stressed here that this method is one of the most effective in analysis of small samples. As a preliminary to a spectrochemical analysis, a rapid crystallographic examination will serve to indicate the number of components present in the sample and their probable nature. These data when correlated with those of the spectrographic examination will often serve to completely identify the sample.

The type of microscope which is used in forensic work depends upon the task at hand. At the scene of a crime a simple hand magnifier or, better, a low-power, detachable, binocular-prism magnifier will be found of great assistance in the examination of minute traces. Blood stains, hair, fibers, fingerprints, dust, powder marks, and other traces can be properly studied and evaluated in the enlarged image.

For ordinary low-power examination at the laboratory a Greenough binocular microscope will be found excellent. Examination of clothing, metal filings, fibers, tears or incisions, clipped wires, tool marks, paper, handwriting, labels, erasures, cloth patterns, etc., should be made with this stereoscopic



microscope at low power. In these observations it will be found that a magnification of greater than 20X usually confuses the eye and contributes no further useful information.

Medium- and high-power work are frequently required in blood and spermatozoa examinations. Metallographic studies are sometimes required in sabotage and accident cases to examine the allegedly weakened structure. Naturally, crystallographic examinations are necessary in the analysis of certain substances such as narcotics. The many biological studies which occur in forensic science are not mentioned here, since that aspect of the laboratory has not been treated extensively in this text.

## 2. THE MAGNIFIER OR SIMPLE MICROSCOPE

In viewing an object the apparent size is determined by the size of the image received on the eye. An object can be observed in greater detail if it is brought

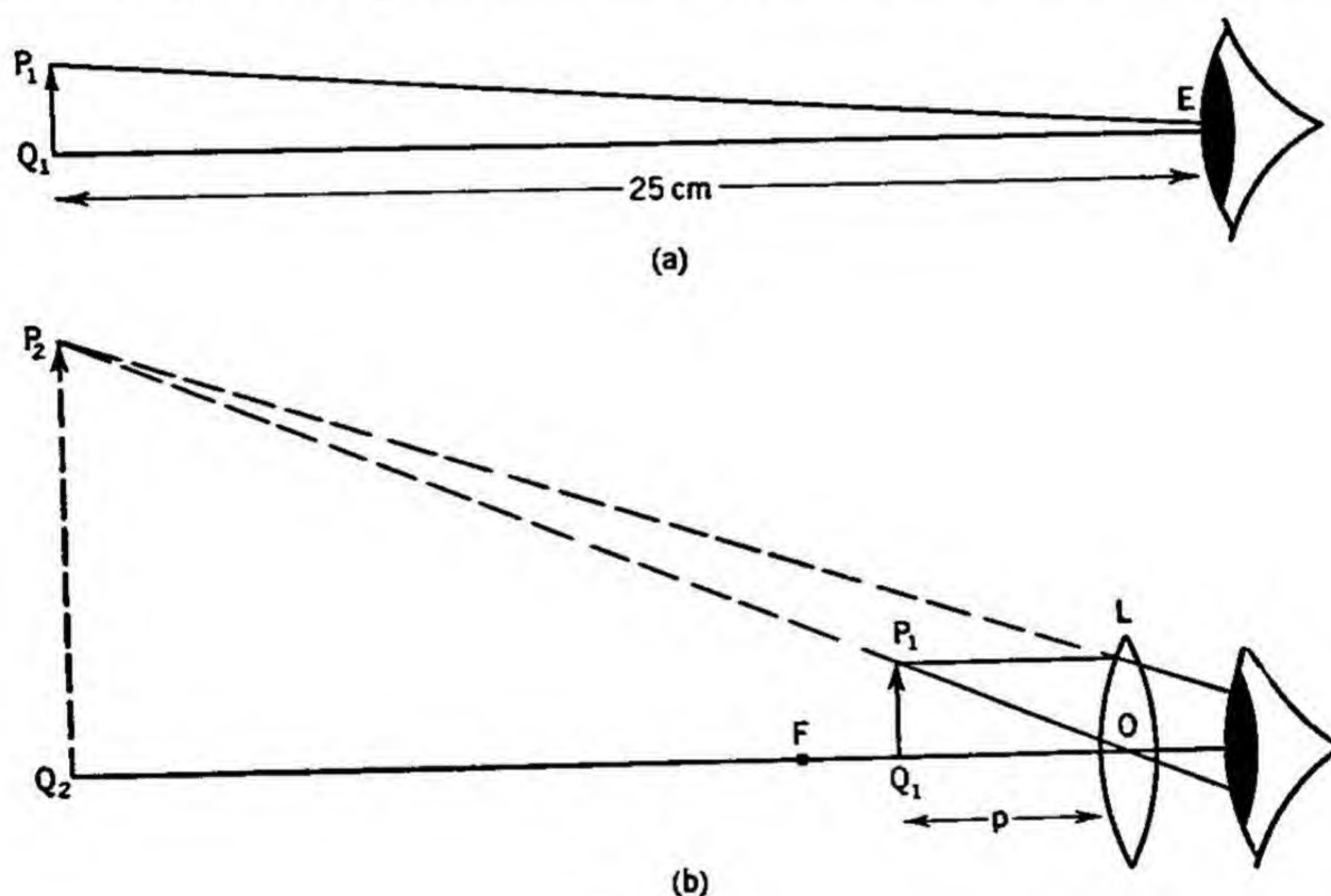


Fig. 235.

closer to the eye so as to give a larger retinal image. The size of the retinal image depends upon the magnitude of the angle which the object subtends at the eye. There is, however, a distance of nearest approach beyond which the eye cannot focus without strain. Within this distance — which is conventionally taken as 25 cm — the rays of light coming from any point in the object are too strongly divergent to be brought to focus. By interposing a convex lens between the eye and the object and bringing the object nearer to the lens than its focal length, a magnified virtual image can be observed (Fig. 235b). A lens or system of lenses designed to accomplish magnification in this manner is called a *simple microscope* or *magnifier*. Some of the magnifiers commonly employed by the criminalistician are shown in Fig. 236.

The magnifying power (*M.P.*) of such a lens is defined as follows:

$$M.P. = \frac{\text{angle subtended at the eye by the image}}{\text{angle subtended at the eye by the object at 25 cm}} \quad (1)$$



In Fig. 235a the object  $P_1Q_1$  is placed at 25 cm from the unaided eye. In Fig. 235b, a lens  $L$  is interposed between the eye and the object  $P_1Q_1$ , yielding the image  $P_2Q_2$ . It is assumed for simplification that the eye is directly behind the lens. The object distance  $p$  is any distance less than the focal length  $F$  of the lens  $L$ . We have, then,

$$M.P. = \frac{\angle P_2OQ_2}{\angle P_1EQ_1}.$$



Fig. 236. Hand magnifiers.

Since the angles are ordinarily relatively small, we may express them in radian measure.

Thus

$$\begin{aligned}\angle P_2OQ_2 &= \angle P_1OQ_1 \\ &= \frac{P_1Q_1}{p}.\end{aligned}$$

In Fig. 235a

$$\angle P_1EQ_1 = \frac{P_1Q_1}{25};$$

hence

$$M.P. = \frac{\frac{P_1Q_1}{p}}{\frac{P_1Q_1}{25}},$$



and 
$$M.P. = \frac{25}{p} \quad (2)$$

Since, from the elementary lens relation,

$$\frac{1}{q} + \frac{1}{p} = \frac{1}{F}, \quad (3)$$

where  $F$  is the focal length, and  $q$  is the image distance; we have on substituting for  $p$ , in equation (2), its value from equation (3)

$$M.P. = \frac{25}{q} + \frac{25}{F}$$

(The sign of  $q$  is changed because the image is virtual.) If the image is formed at 25 cm, i.e.,  $q = 25$ , we have

$$M.P. = 1 + \frac{25}{F} \quad (4)$$

When the image is at infinity,

$$M.P. = \frac{25}{F} \quad (5)$$

Since  $F$  is usually small in comparison, the image distance does not substantially affect the magnifying power. If  $F = 1$  cm, the magnifying power lies between the limits 25 and 26; hence in using a hand magnifier the difference in magnifying power brought about by varying the image distance is negligible. There is, however, an advantage of illumination in holding the lens close to the eye.

### 3. THE COMPOUND MICROSCOPE

In Fig. 237 the principal parts of the compound microscope are illustrated. Since the various parts are usually known to science students or are easily identifiable with a microscope at hand, reference will be made to many of them without further explanation.

The two essential elements of a microscope are the objective and the ocular. These are illustrated schematically in Fig. 238. The object which is under examination is placed just beyond the lower focal point of the objective lens. An er

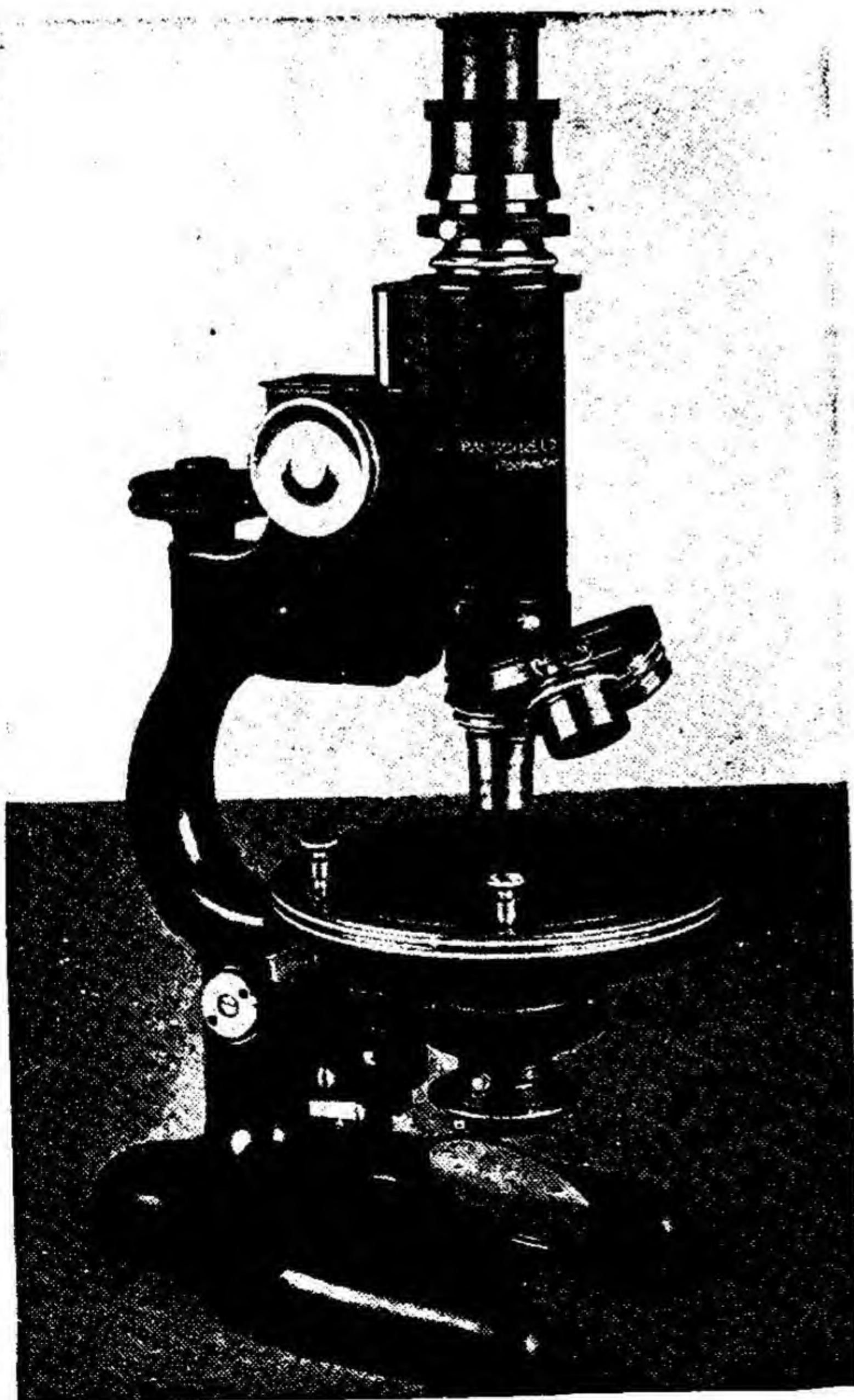


Fig. 237. A compound microscope.



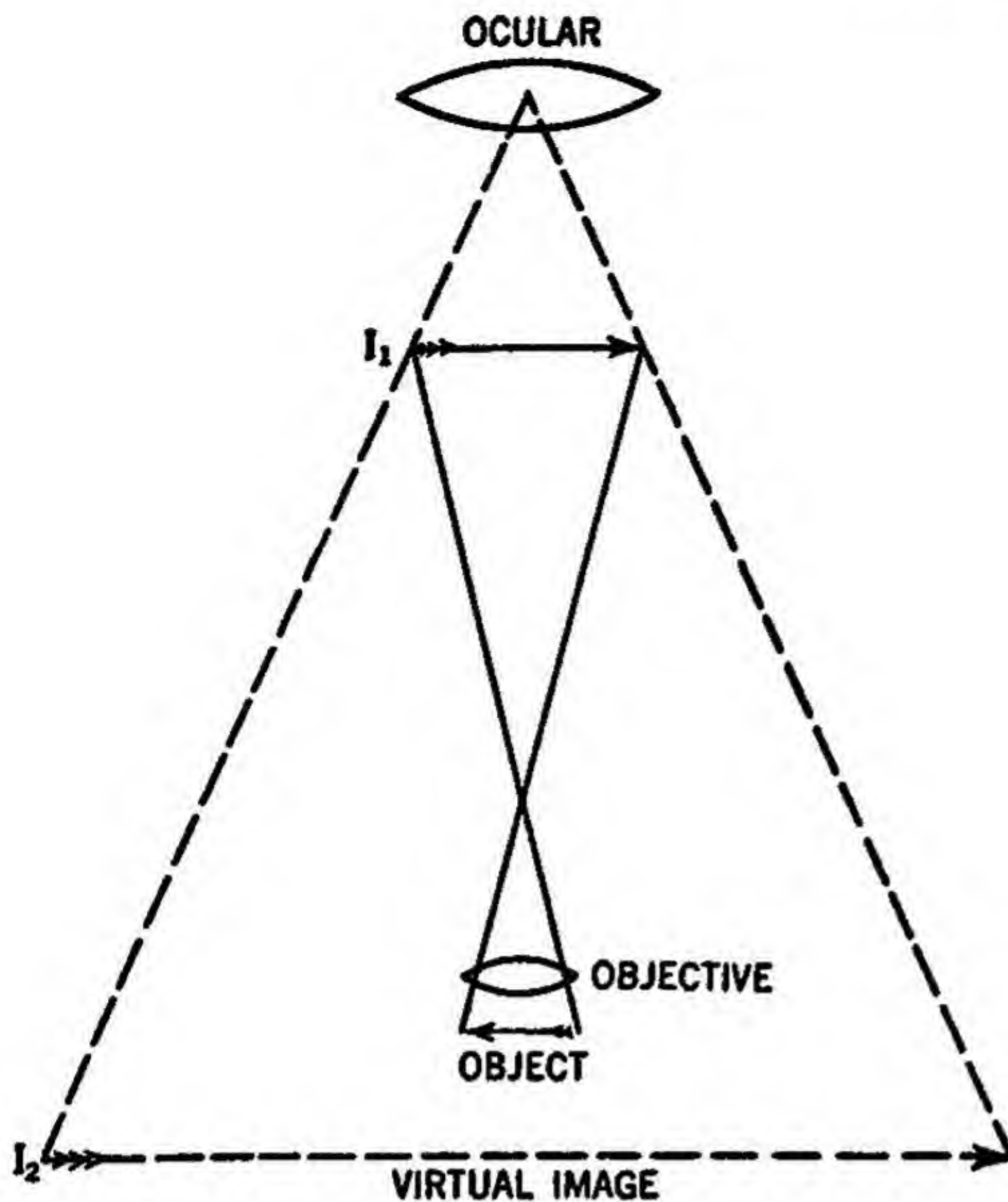


Fig. 238. Schematic diagram of the compound microscope.

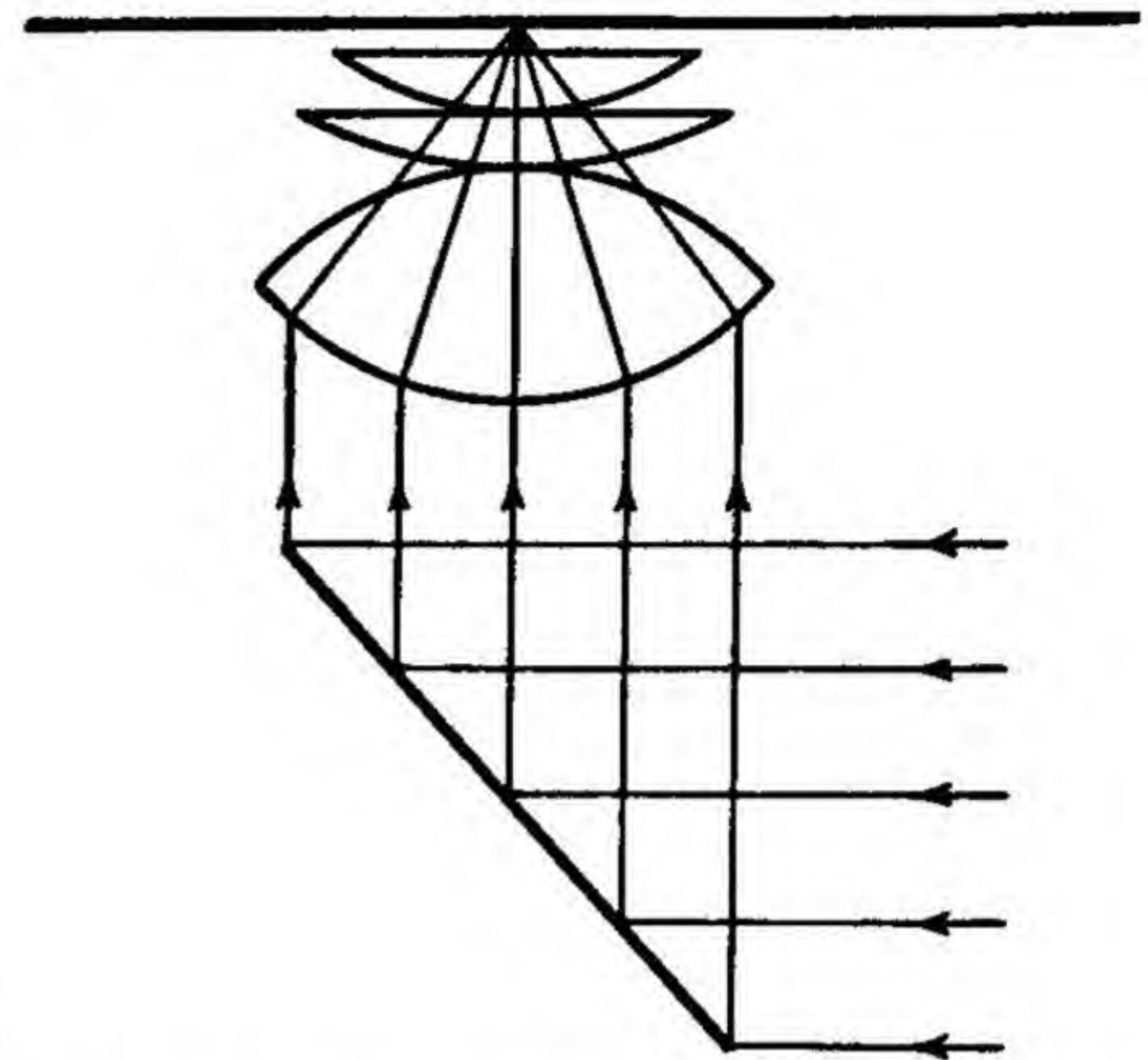


Fig. 239. The condenser and plane mirror.

larged real image of the object is formed at  $I_1$ . The plane  $I_1$  is located just within the lower focal plane of the ocular. The image  $I_1$  now serves as an object for the ocular, and an enlarged virtual image of  $I_1$  is formed at  $I_2$ .

The function of the condenser is to illuminate the object suitably for the purpose of the observer. Figure 239 illustrates the use of the condenser for concentrating light on the subject. A mirror is used with the condenser when the microscope is in the vertical position. For objectives of power higher than 10X, the plane side (as in Fig. 239) is used with the condenser. For lower-power objectives the condenser may be swung out and the concave side (Fig. 240) of the mirror used.

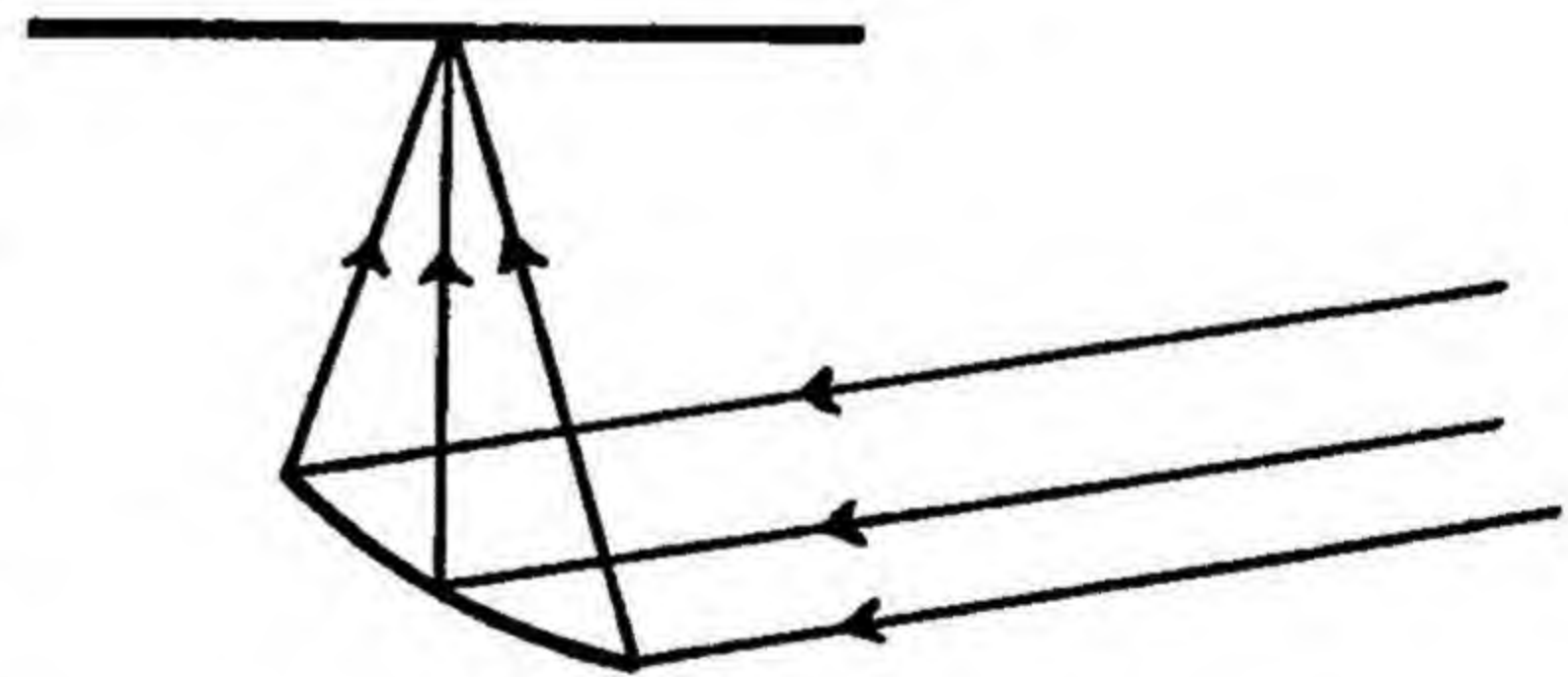


Fig. 240. The concave mirror.

Before discussing these microscope parts in detail a brief treatment of the subjects of numerical aperture and resolving power is given because of the basic concepts which they contain for the understanding of an optical system.

#### 4. NUMERICAL APERTURE

In any optical system — microscope, telescope, or camera — the amount of light forming the image is limited by either a lens or a diaphragm. This limiting element is called the *aperture stop* of the system. In a camera the diaphragm is the aperture stop. In a microscope objective the rim of one of the lenses is the aperture stop. The image of the aperture stop in the object space is called the *entrance pupil* of the system; the image of the aperture stop in the image space



is called the *exit pupil*. In other words, the entrance pupil is the image of the aperture stop formed by the lens or lenses in front of the aperture stop; and the exit pupil is the image of the aperture stop formed by the lenses in back of the aperture stop. From the fact that the entrance and exit pupils are each conjugate to the aperture stop, it is obvious that they are conjugate to each other with respect to the entire optical system; i.e., an object placed at any of the three positions would be imaged at the other two.

In Fig. 241 let  $D$  be the aperture stop,  $E_n$  the entrance pupil, and  $E_x$  the exit pupil for a point  $P$  on the axis, the image of which is  $P'$ . It can be seen that

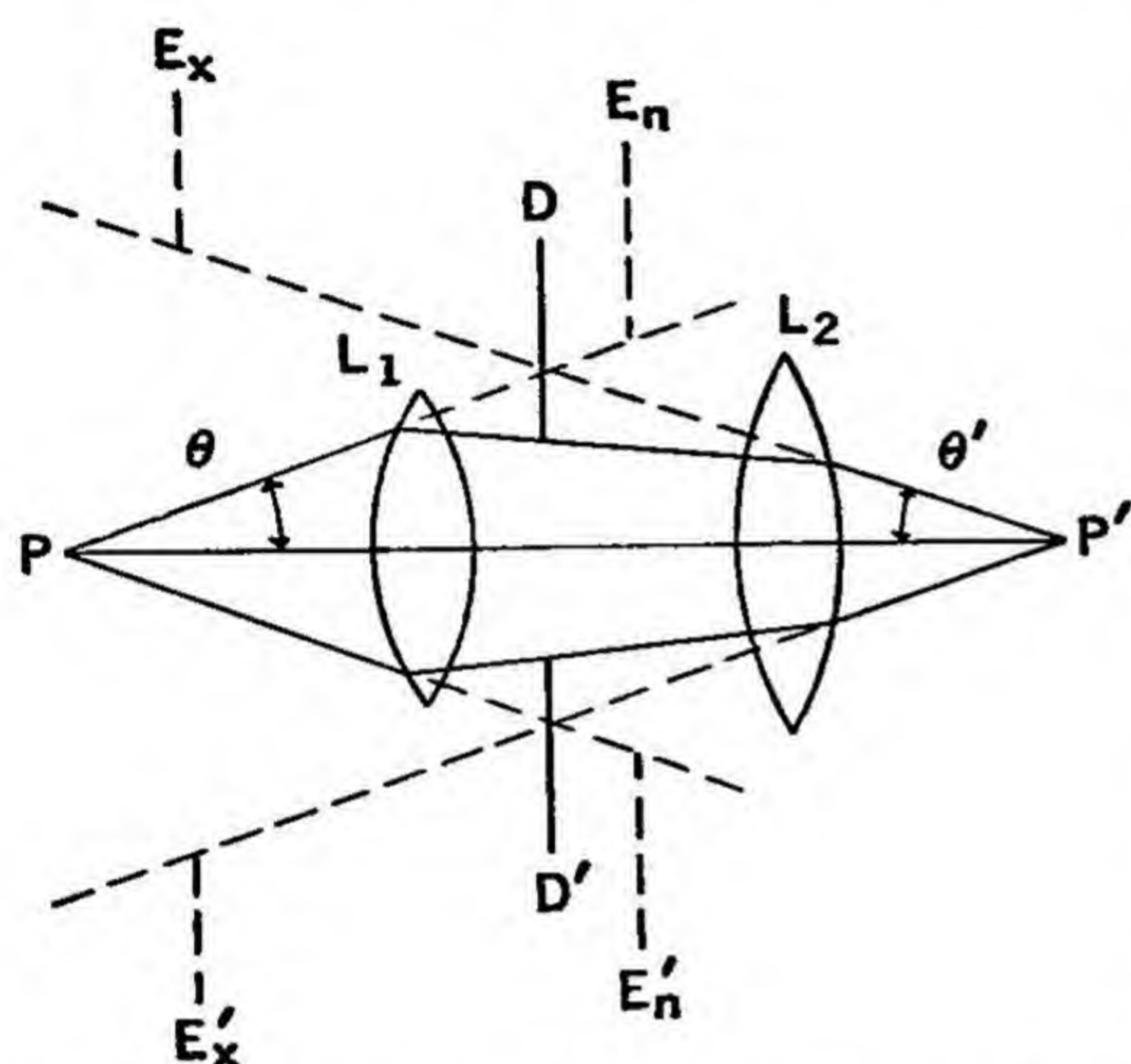


Fig. 241. Aperture stop, entrance and exit pupils.

rays which, after refraction, will pass through  $DD'$  would, if unrefracted, pass through  $E_nE_n'$ . Hence the pencil of image-forming rays makes a half-angle  $\theta$  at the point  $P$ . The angle  $\theta$ , which is the angle subtended at  $P$  by one-half the entrance pupil, is a measure of the light illuminating the final image. A ray making an angle greater than  $\theta$  cannot pass through the system. For various purposes this angle is measured in different ways. *Relative aperture* is the general term for such a measure. In photography the relative aperture is called the *f/number*, which is defined as the ratio of the focal length to the diameter of

the entrance pupil. The *f/number* is used as a measure of the illumination falling on the photographic plate (Chap. 12).

In microscopy, the measure used is the *numerical aperture (N.A.)*, which is defined thus:  $N.A. = n \sin \theta$ , where  $n$  is the refractive index of the object space, i.e., of the medium through which light travels from the object to the lens. It can be shown that the illumination is directly proportional to the square of the numerical aperture and inversely proportional to the square of the magnification.

## 5. RESOLVING POWER

In microscope objectives the aperture stop is usually the rim of the lowest lens. Thus we may designate the numerical aperture of the objective by

$$N.A. = n \sin \theta, \quad (6)$$

where  $\theta$  is the half-angle of the outermost rays entering the lens and  $n$  is the refractive index of the medium in which the object lies. (This is the maximum available numerical aperture; in practice the *N.A.* is less than this value.) The obliquity of these limiting rays is shown in the more extended theory to be a measure of the resolving power of the objective; i.e., it controls the linear separation  $R$  of two point objects which can just be resolved by the microscope.



It can be shown that the limit of resolution, when axial transmitted illumination is used, is expressed by

$$R = \frac{0.61\lambda}{n \sin \theta}, \quad \text{or} \quad R = \frac{0.61\lambda}{N.A.}, \quad (7)$$

where  $\lambda$  is the wave length of the light used in illuminating the object.

From equation (7) we can see that the limit of resolution can be decreased by increasing the  $N.A.$  However, the maximum value which  $\sin \theta$  can have is unity. The refractive index usually lies between  $n = 1$  and  $n = 1.5$ . Decreasing  $\lambda$  by using light of shorter wave length (e.g., ultraviolet light) aids in resolution; but this procedure too is restricted to the limit of visible light. Thus, although it is possible to increase the magnifying power of a microscope indefinitely by decreasing the focal lengths of the objective and ocular, the limitations set on resolving power by the factors in equation (7) make excessive magnification a fruitless operation.

## 6. OBJECTIVES

### Designation

Objectives are designated according to focal length, numerical aperture, magnification, and corrections (achromatic, apochromatic, etc.). They range in focal length from 48 mm,  $N.A.$  0.08, to about 3 mm,  $N.A.$  1.40. Objectives of focal length less than 4 mm are usually of the immersion type. Special objectives are available for dark-field work and vertical illumination.

### Corrections

An objective is usually corrected for one image distance and hence for one tube length. The more expensive microscopes have adjustable draw tubes with engraved scales. Achromatic objectives are corrected to eliminate chromatic aberration for two wave lengths, and spherical aberration for one wave length. (Chromatic aberration — rays of different color do not have a common focus. Spherical aberration — rays from inner and outer areas of the lens do not have a common focus.) Apochromatic objectives are corrected to eliminate chromatic aberration for three wave lengths, and spherical aberration for two. This latter type of objective is quite expensive. A compromise in corrections and price is achieved in the semiapochromatic objective, in which fluorite is used for some of the elements.

By correcting spherical aberration it is possible to image every point in the field sharply, but the resulting total image is a curved field; the position of focus must be changed in examining the center and edge of the field. Particularly in high-aperture objectives is this defect noticeable because of the small depth of field; hence resolving power is sometimes sacrificed in favor of a lower-power objective which gives a flatter field. We shall see later that some oculars are designed to aid in flattening the field.



### Immersion Objectives

We have already seen that, since  $N.A. = n \sin \theta$ , the numerical aperture (and the resolving power) of an optical system can be increased by observing the object in an object space of higher refractive index,  $n$ . Water ( $n = 1.3$ ) and cedar wood oil ( $n = 1.5$ ) are the most commonly used liquids for this purpose. A drop of liquid is placed at the objective and the condenser to form a continuous medium for the light from condenser to objective. Water is used by biologists, since it is a natural medium for many of the objects which they study.

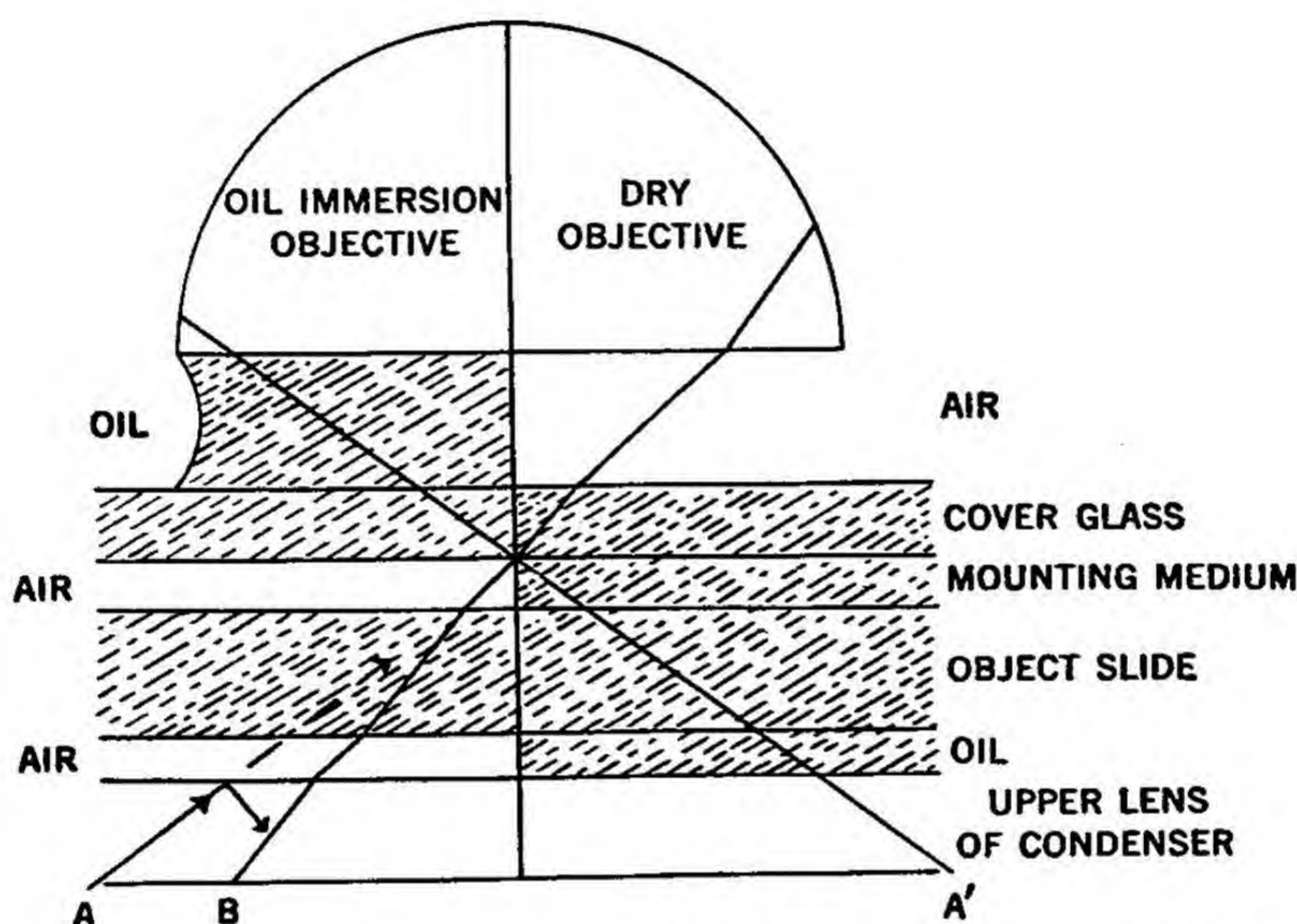


Fig. 242. The paths of rays entering the immersion and the dry objective.

The effect of an immersing medium on numerical aperture can be seen from Fig. 242. Ray  $A$  from the condenser cannot enter the dry objective because it is reflected at one of the intermediate surfaces. The corresponding ray  $A'$  enters the immersion objective because it travels through a medium of higher refractive index. Hence by means of the immersion medium, rays of greater obliquity are used and the effect is that of an increased numerical aperture.

### Focusing

With the substage diaphragm stopped down for a narrow cone of light, the objective is lowered by means of the coarse adjustment until it is within its own focal length distance from the slide. The mirror is adjusted until the field is bright as observed in the microscope. Using the coarse adjustment, the tube is raised until the specimen is in focus. The focus is then improved by means of the fine adjustment. With an unknown specimen the low-power objectives should be used first.



## 7. OCULARS

The purpose of the ocular is to form an enlarged, virtual image for the eye (or an enlarged, real image for the photographic plate) from the real image formed by the objective. The two types in most common use are the Ramsden or positive eyepiece, and the Huygenian or negative eyepiece. They may be readily distinguished by the fact that the Ramsden eyepiece can be used as an ordinary magnifier to examine an object. It is possible for a single lens to perform the elementary function of an eyepiece; certain other requirements, however, must be fulfilled: (a) the eye should be immediately behind the eye lens to avoid extraneous light; (b) spherical aberration must be avoided and, if possible, an additional flattening of the field contributed; (c) chromatic aberration must be avoided and, if possible, residual chromatic aberration from the objective corrected. These additional aims can only be achieved by a more complex arrangement of lenses. The upper lens (or combination of lenses) of an ocular is called the *eye lens*; the lower lens is called the *field lens*.

### Ramsden Eyepiece

In its simplest form this consists of a combination of two convex lenses of equal focal length separated by a distance equal to two-thirds of this focal

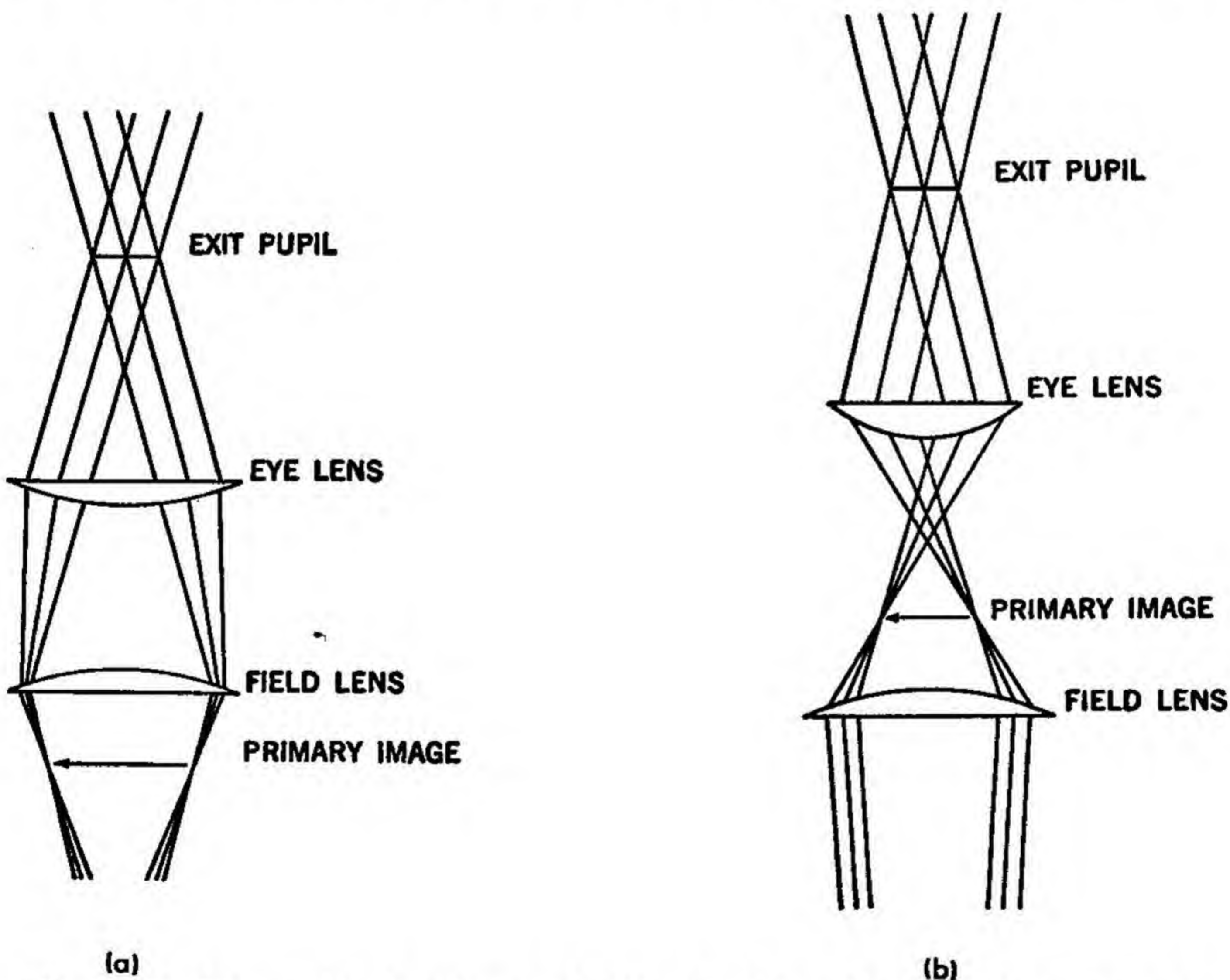


Fig. 243. The optical system of: (a) the Ramsden ocular; (b) the Huygenian ocular.

length. In use with the microscope it usually assumes the form of an achromatic doublet or triplet.



The real image from the objective is formed outside of the field lens of the Ramsden eyepiece at the lower focal plane of the ocular (Fig. 243a); hence this ocular is excellently adapted to use with cross hairs. For micrometric work it has the advantage of subjecting the image and the cross hairs equally to any distortion that may exist in the combination.

### Huygenian Eyepiece

In this ocular the image formed by the objective lies between the eye lens and the field lens, and serves as a virtual object for the eyepiece (Fig. 243b). The field lens reduces the size of the image formed by the objective, but increases the brightness and the area visible. The eye lens, focused on this image, increases the magnification. If cross hairs are provided, they will lie between the lenses in the plane of the image formed by the field lens.

Freedom from distortion is about equal in the Ramsden and Huygenian eyepieces. The Ramsden will give a flatter field. Because of the difficulty in correcting Huygenian oculars, their magnification seldom exceeds 12X; hence the Ramsden is used for greater magnification.

### Correction of Oculars

In the image formed by an apochromatic objective the blue and red components are magnified to a different degree; thus we have two images of different color which do not coincide. This chromatic aberration is corrected by means of what are called *compensating oculars*. For low-power work the Huygenian is used. The use of the Ramsden becomes important when high-power work is done with an apochromatic objective.

Curvature of the field is another aberration which is not entirely eliminated by an objective. When flatness of field is more important than achromatism, an ocular especially designed for this purpose may be used. Trade names such as "Hyperplane" and "Periplan" are used to designate these flat-field eyepieces.

### Magnification

We have seen that the magnifying power of an eyepiece (magnifier) is given by  $M.P. = \frac{250}{F}$ , (equation 5) where  $F$  is the focal length of the combination in millimeters. Low-power eyepieces have a magnification of 5X, 10X, or 15X; high-power eyepieces may range up to 30X. The use of high-power oculars yields empty magnification except in unusual cases where an objective is used of which the N.A. is large in comparison with the focal length. For ordinary work a 10X or 15X will be found satisfactory.

## 8. CONDENSERS

### Selection

In its simplest form the substage condenser is a convex lens which forms an image of a light source in the object plane. The primary function of the con-



denser is to illuminate the object adequately for the objective and for the purpose of the examination. A condenser should always be used with an objective of focal length less than 24 mm in order to fill the objective with a cone of light. The selection of the condenser is guided by the choice of objective. To provide the proper convergence of light for an objective, the *N.A.* of the condenser should equal the *N.A.* of the objective. If this condition is not fulfilled, the available resolving power of the objective will not be realized.

We may classify condensers as follows: the Abbé condenser, with one or two uncorrected lenses; the aplanatic condenser, which has superior correction for flatness of field; and the achromatic condenser, which is corrected for chromatic and spherical aberration. The *N.A.* of condensers varies from 0.2 to 1.0 for dry objectives. For immersion objectives special condensers with *N.A.* of 1.2 to 1.4 are used. Dark-field condensers will be described later.

### **Focusing**

The focusing of the condenser depends upon the method of illumination. When the large diaphragm is close to the lamp lens, which is used as a secondary source of illumination, the condenser is focused by focusing an image of the lamp diaphragm in the plane of the object. To accomplish this, the objective is first focused as described above. With the lamp at a distance of about 15 inches, the lamp diaphragm is stopped down. By tipping the mirror and manipulating the focusing adjustment of the condenser, an image of the edge of the diaphragm can be brought into view in the microscope. With the condenser at its topmost position, it can be lowered until the diaphragm is sharply focused.

### **Centration**

The objective and condenser must be carefully aligned for exacting work. Alignment of the objective has not been treated since few microscopes are equipped with an adjustment for this purpose. To align the condenser with respect to the objective, the ocular is removed and a pinhole cap inserted in its place. The condenser diaphragm can now be observed in the upper focal plane of the objective. With the diaphragm stopped down until it is visible in this plane, the circle of the diaphragm is now made concentric with the objective circle by manipulating the centering screws.

## **9. DIAPHRAGMS**

### **Field Diaphragm**

This is an iris diaphragm used to limit the area of the object visible. For this purpose it is so situated that its image will lie in the plane of the object or its image (Fig. 244). A field diaphragm can be located in the eyepiece  $F_1$ , in the plane of the object  $F_2$ , or immediately in front of the illuminant (not shown in the illustration). This last position will be the one with which we shall concern ourselves, since it is the most common. It will be noticed that the three positions are mutually conjugate with respect to the intervening lenses; that is, an object



placed in one position will be imaged at the other two. They are conjugate too, with respect to positions  $F_3$  and  $F_4$  in the diagram. The adjustment of the field

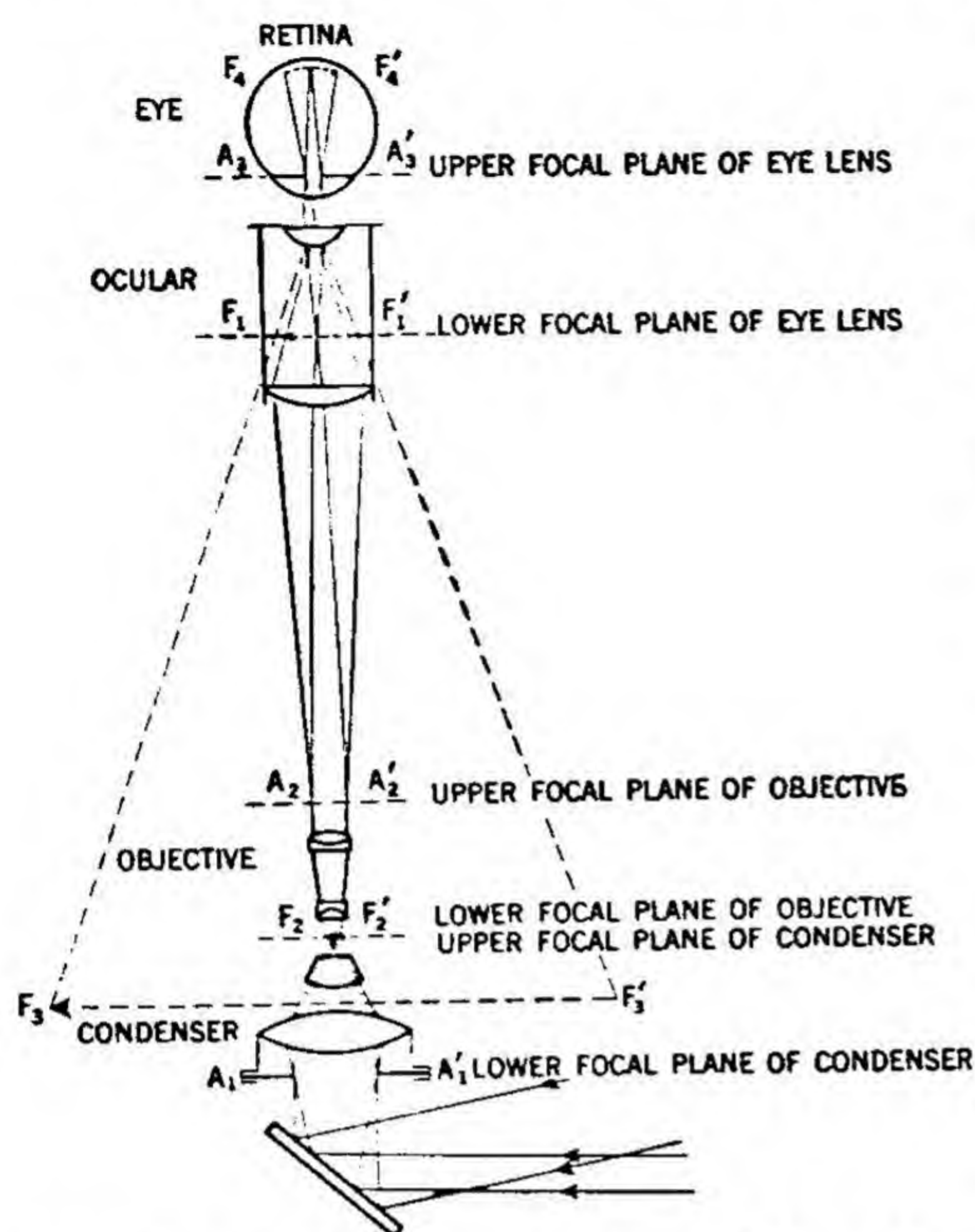


Fig. 244. Schematic diagram of the microscope showing the positions of the various diaphragms.

determines the effective  $N.A.$  To accomplish its purpose an aperture diaphragm may be placed in the lower focal plane  $A_1$  (Fig. 244) of the condenser or the upper focal plane  $A_2$  of the objective (to control, in addition, depth of field). The iris  $A_3$  of the eye also acts as an aperture diaphragm. It will be seen again that when the microscope is properly adjusted, these three positions are mutually conjugate with respect to the intervening optical systems.

Of the three, the most important is the substage diaphragm of the condenser. Since this is at the lower focal plane of the condenser, its image formed by the condenser will be at infinity; the objective, receiving the image by parallel rays, will form another image at its upper focal plane. It is for this reason that the aperture diaphragm may be seen by looking into the tube with the eyepiece removed. (Its adjustment can be controlled by observing it in this manner.)

Previously it has been stated that the objective, when properly used, should act as the aperture stop of the microscope and the  $N.A.$  of the condenser should approximate the  $N.A.$  of the objective. Stopping down the diaphragm decreases the  $N.A.$  of the condenser. The correct opening ( $AA'$  in Fig. 245), then, of the diaphragm would approximately fill the aperture of the objective; a slight further reduction in the opening ( $BB'$  in Fig. 245) would give a decrease in the obliquity of the rays of light which would result in a condition where the full aperture of the objective is not utilized. Thus in Fig. 245 the actual  $N.A.$  is  $n \sin \theta$ ; whereas the available  $N.A.$  is  $n \sin \theta'$ .

diaphragm is one of the preliminary steps in a microscopic examination. When the diaphragm is considerably stopped down, its image may be seen in the ocular, if the substage condenser is properly focused. The diaphragm is then opened until the field is just cleared. In this position extraneous glare is avoided. Further decrease in intensity is accomplished by the use of neutral filters.

### Aperture Diaphragm

This is an iris diaphragm which controls the angular aperture of the cone of light transmitted by a lens. When the diaphragm is partially stopped down, the peripheral area of the lens does not receive light and the emerging cone has a smaller apex angle. The diaphragm then becomes the aperture stop of the lens and de-



According to the Abbé theory, the greatest resolving power is obtained when the substage diaphragm is adjusted so that the aperture of the objective is two-thirds filled (as seen by looking down in the tube with the ocular removed.) Deviations from this theoretically optimum position should be tried to suit the purpose of observer. If the diaphragm has too great an opening, the subject will be seen in a glare of light; if the opening is too small, resolution will suffer because the objective is not properly used. The substage diaphragm should not be employed to control the intensity of light; neutral filters should be used for this purpose.

### 10. DEPTH OF FIELD \*

The depth of field of any optical system is inversely proportional to the magnification. In the microscope the depth of field  $d$  is given by

$$d = \lambda \frac{\sqrt{n^2 - (N.A.)^2}}{(N.A.)^2} \quad (8)$$

Hence, where  $N.A.$  (objective) is small we may say that depth of field is inversely proportional to the square of  $N.A.$  The depth of field of a microscope is very small. It is aided greatly in visual work by the power of accommodation. In photomicrography, however, there is no assistance given by the eye and the depth of field is much less.

In selecting an objective for depth of field it should be remembered that depth of field can be gained only by sacrifice of more desirable qualities such as great  $N.A.$  and good correction. The use of diaphragms to increase depth of field is permissible in ordinary photography where resolving power is not in question; in microscopy, however, reducing an aperture diaphragm opening reduces the resolving power.

An increase of depth of field  $d$  can be achieved by use of an appropriate mounting medium. The depth of field  $d$  of a subject in air is increased to a depth of  $dn$  when immersed in a medium of refractive index  $n$ .

### 11. ILLUMINATION OF TRANSPARENT OBJECTS

Transmitted light is ordinarily used to illuminate transparent specimens. The following are the more common types of illumination for this purpose:

\* See Chap. 12.

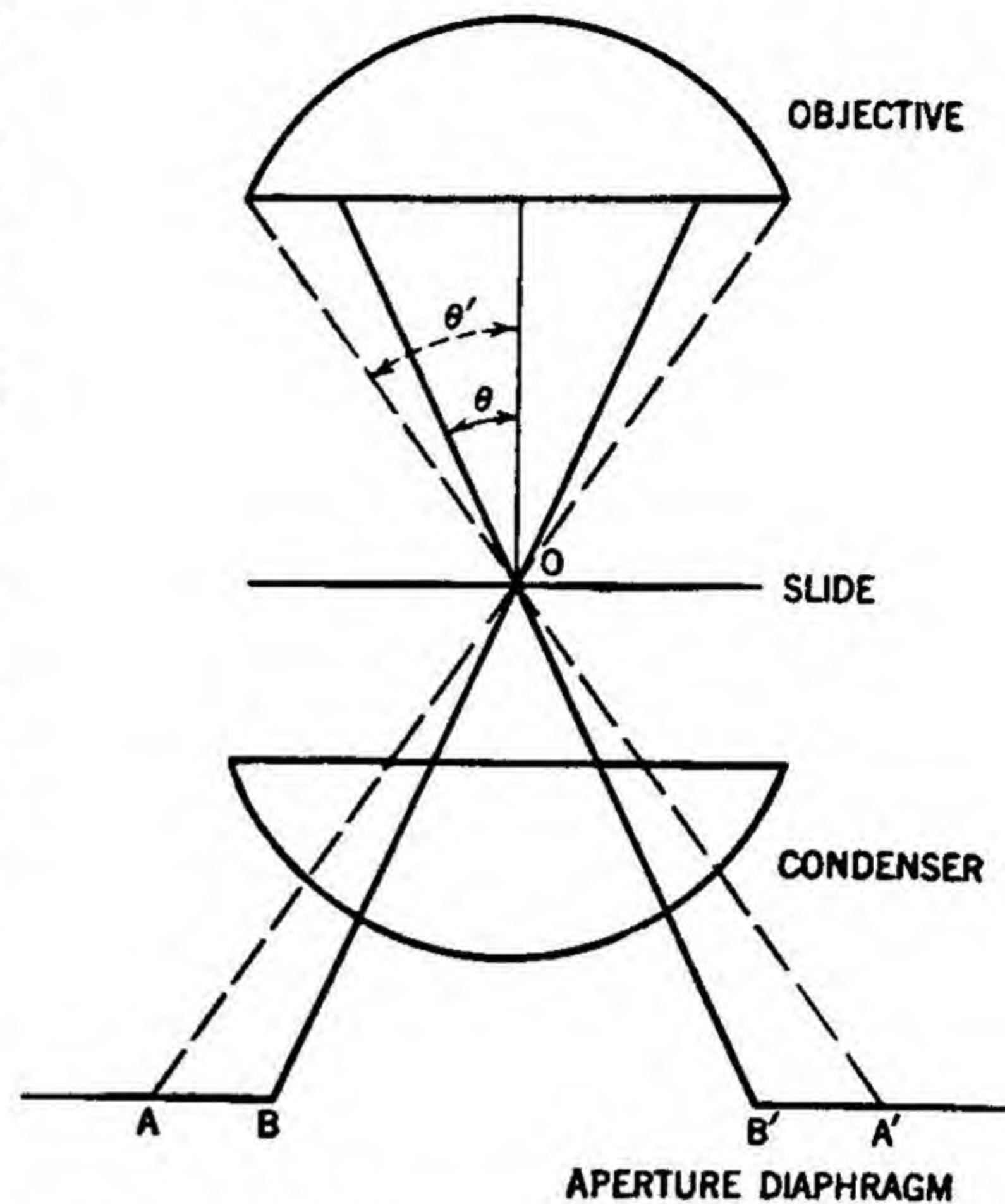


Fig. 245. The effect of "stopping down" the aperture diaphragm of the condenser.



### Bright-Field Illumination

If a beam of light is transmitted through the object by means of a substage condenser the image appears on a bright, well-illuminated field. By manipulating the mirror, the substage diaphragm, and the condenser, the light can be varied in the following ways:

(a) Axial Illumination — By using the plane side of the mirror without a condenser, parallel rays of light can be made to enter the microscope. This lighting is characterized by increased contrast and a decrease in resolution due to the omission of oblique rays. It is used with objectives of focal length 35 mm or greater.

(b) Convergent Illumination — This lighting is achieved by focusing the condenser so that its upper focal plane lies in the plane of the object. This is the most common method of lighting in medium- and high-power work, and has been assumed in previous descriptions of the use of the condenser.

### Oblique Illumination

The symmetrical lighting described above is sometimes inadequate to enable the observer to visualize the relations of various surfaces of the object. For this purpose a decenterable substage diaphragm can be used to give an unsymmetrical lighting which by its shading emphasizes edges, fissures, and fine structure. This lighting is very useful in the examination of hair, fibers, textiles, crystals, and drugs.

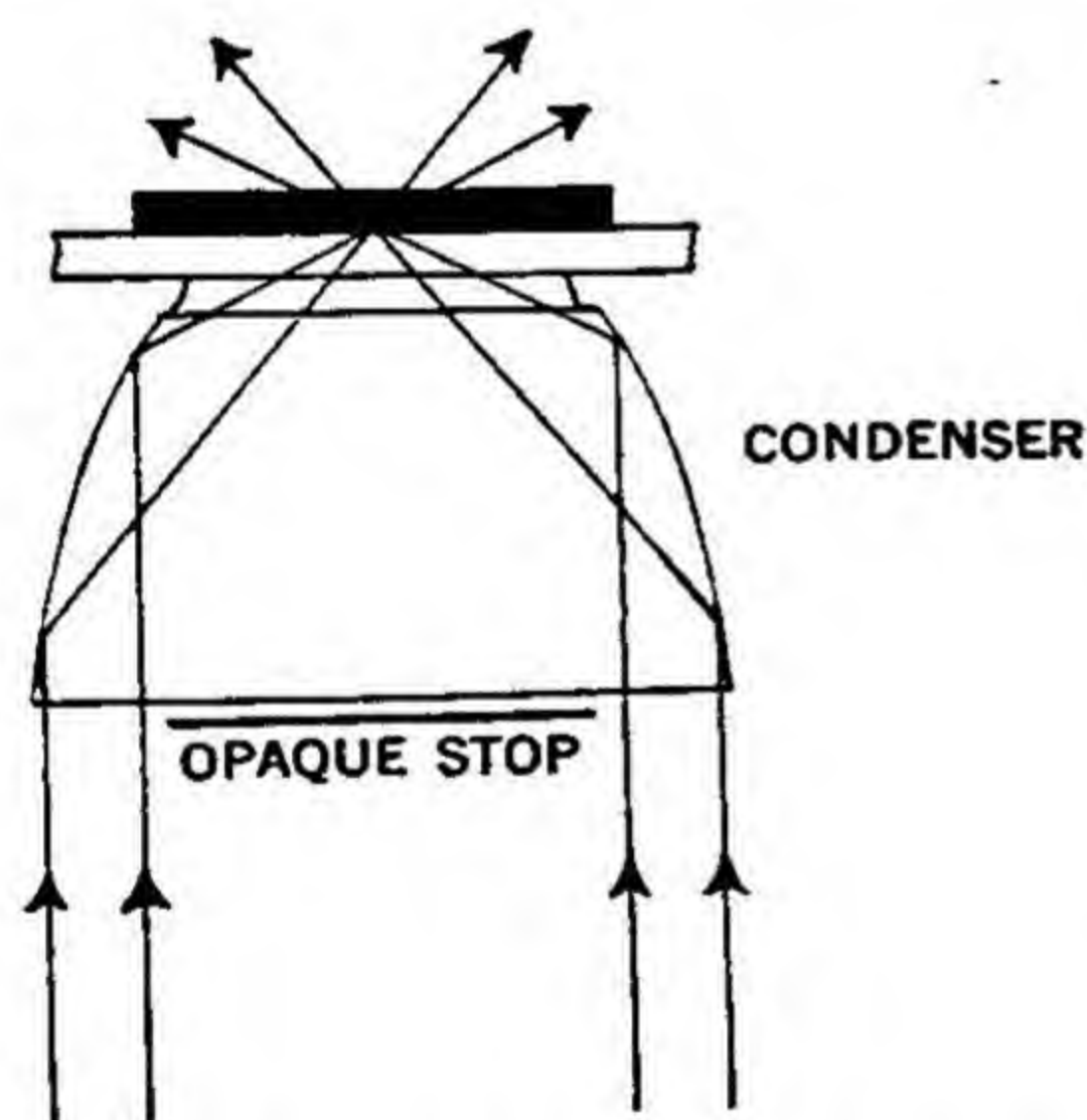


Fig. 246. The paraboloid condenser.

### Dark-Field Illumination

In this lighting the object appears bright against a dark background. It is used to reveal objects which are too transparent or too small to be seen against a bright field. A condenser is employed in which the central rays are cut off. Very oblique rays strike the object. Some of the rays are refracted and reflected by small particles into the objective. The other rays do not enter the objective (Fig. 246). The *N.A.* of the objective must be lower than that of the condenser. A funnel stop inserted in the

back of the objective or an iris diaphragm will lower the *N.A.* of a high-power objective.

The following two methods may be used to obtain dark-field illumination:

- (a) Dark-Ground Stop — The ordinary substage condenser is used with a central disk or dark-ground stop. The objective with this method should be 16 or 18 mm in focal length.
- (b) Special Condensers — A condenser which supplies a hollow cone of rays is used in high-power work. The paraboloid (Fig. 246) and cardioid condensers are the most common type, the former being used with



medium-power objectives and the latter with high-power. Oil is always used between the condenser and the slide.

## 12. ILLUMINATION OF OPAQUE OBJECTS

Overstage lighting must be used for objects which are too opaque for transmitted light. For low-power work and work with rough surfaces the method described on pp. 549–550 is suitable. In medium- and high-power work with flat surfaces it is necessary to send light through the objective. A device for this purpose is called a *vertical illuminator*. Light is directed into the side of the microscope and deflected downward by means of a glass plate or prism. The objective serves as a condenser. The usual aperture and field diaphragms are used. Vertical illuminators find their greatest use in metallographic microscopy.

## 13. METHODS OF ILLUMINATION

It is not possible to obtain with a microscope results which are even moderately successful unless the object is illuminated with great care. For low-power work on opaque objects ordinary photoflood lamps are satisfactory if they are carefully placed. However, for high-power work on transparent objects another method is necessary. For this purpose an illuminant equipped with an auxiliary or *bull's eye* condenser is employed. A diaphragm is located in front of the lens. Two methods of illumination are in common use.

### Imaging the Light Source in the Plane of the Object

When the light source is at the focal point of the bull's eye condenser, parallel rays emerge, strike the plane mirror of the microscope, and enter the

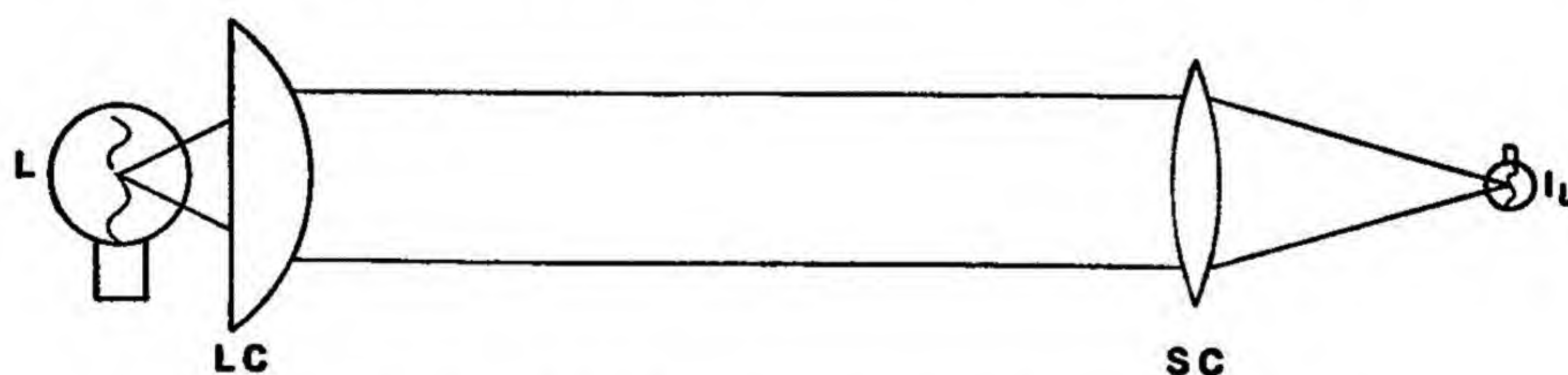


Fig. 247. Imaging the light source in the plane of the object.

substage condenser. If the condenser is in focus for parallel rays on the object plane, an image of the light source will be in focus there (Fig. 247).

### Köhler Illumination

This is the most popular method of illumination for high-power work. It consists in imaging the light condenser in the plane of the object (Fig. 248). To do this the light source itself is moved beyond the principal focus of the condenser lens. An image of the source is formed on the substage diaphragm and observed either by closing down the diaphragm or placing a piece of paper in



front of it. A field diaphragm in this illumination is situated as closely as possible to the bull's eye condenser lens. The two may then be considered to be in one plane. The substage condenser is now focused so that an image of the diaphragm is formed on the object plane. This is observed by stopping down the field

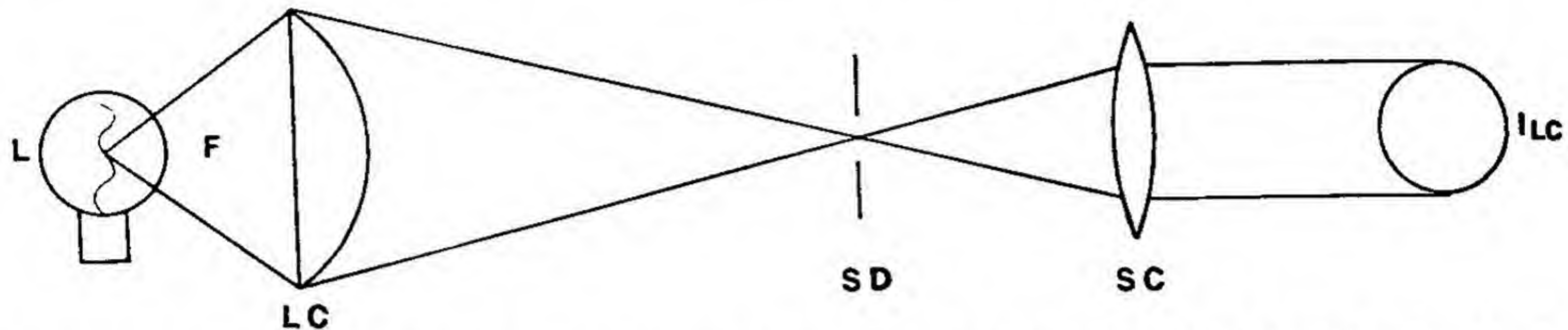


Fig. 248. Imaging the lamp condenser in the plane of the object (Köhler illumination).

diaphragm and looking into the ocular for the black outline. Since the light source was focused in the plane of the aperture diaphragm, it should now be possible to observe its image by removing the ocular and looking at the back lens of the objective.

#### 14. PROCEDURE IN USING THE MICROSCOPE

Throughout the above descriptions recommendations have been made for the proper use of each part of the microscope. These suggestions are integrated in the following summary. It is assumed that a symmetrical, bright-field examination is being made. The procedure will be described for both methods of illumination: (a) imaging the light source in the object plane and (b) imaging the illuminating condenser lens in the object plane (Köhler Illumination). It is assumed that the object slide has been prepared and that a cover glass of proper thickness is being used. We begin with both diaphragms fully opened and aperture diaphragm approximately centered with respect to its mount.

##### Light Source Imaged in Object Plane

1. Adjust the lamp for parallel rays by focusing on a wall about 25 ft away. Illuminate the plane side of the mirror with a parallel beam of light.
2. Looking at the objective and stage from the side, lower the objective until it is at a point very close to the object slide. With the eye at the ocular adjust the mirror until the light is visible. Raise the objective to rough focus by coarse motion, using the fine motion to raise and lower about the point of fairly satisfactory focus.
3. Partially stop down the field diaphragm and, by focusing the substage condenser, obtain its image in the field of view.
4. By adjusting the mirror, center the image of the field diaphragm in the field of view.
5. Clear the field, i.e., open the field diaphragm until its image just disappears from the field of view.



6. Partially stop down the aperture diaphragm. Remove the ocular and observe its image in the back lens of the objective. Center this image by adjusting the aperture diaphragm. Open the aperture diaphragm until two-thirds of the back lens is filled with light.
7. With the ocular replaced, examine the image and make final adjustments, viz., fine focus, filters, choice of field, etc.

### Image of Condenser Lens in Object Plane (Köhler Illumination)

In step (1) a parallel beam is not necessary. After step (2) of the above procedure focus the condenser lens of the illuminant so that an image of the light source is seen in the plane of the aperture diaphragm. This can be done with the diaphragm stopped down. The front lens of the substage condenser should be uniformly filled with light in order that the available *N.A.* of the object can be used.

## 15. NORMAL MAGNIFYING POWER

In order to determine the most useful magnification at which a microscope is used, it is necessary to consider the *normal magnifying power* of the instrument. The definition of this term is given by the relation:

$$\text{Normal magnifying power} = \frac{\text{N.A. of objective}}{\text{N.A. of eye}} \quad (9)$$

If the pupillary diameter is taken as 2 mm, the *N.A.* of the eye for an object in air at 250 mm (normal viewing distance) is given by

$$\text{N.A.} = n \sin \theta = 1 \times \frac{1}{250} = 0.004.$$

From equation (7) the limiting separation of two points which are just distinguishable at this distance when viewed with monochromatic yellow light ( $\lambda = 550 \text{ m}\mu$ ) is

$$R = \frac{0.61\lambda}{n \sin \theta} = \frac{0.61 \times 5.5 \times 10^{-4}}{0.004} = 0.08 \text{ mm.}$$

For two objects which can just be distinguished by a microscope objective of *N.A.* = 0.95, the linear separation is

$$R = \frac{0.61 \times 5.5 \times 10^{-4}}{0.95} = 0.0003 \text{ mm.}$$

The *N.A.* of the objective in this case is  $\frac{0.95}{0.004}$  or 240 times the *N.A.* of the unaided eye; hence to fully utilize the available resolving power of this objective, the magnifying power of the microscope should be at least 240, i.e., the normal magnifying power in this case.



In general, we have

$$\begin{aligned}\text{Normal magnifying power} &= \frac{N.A. \text{ of objective}}{0.004} \\ &= 250 \times N.A. \text{ of objective.}\end{aligned}\quad (10)$$

If a magnifying power lower than  $250 \times N.A.$  is used it will not be possible to see all the available detail. Using a higher magnifying power will reveal no additional detail and will be attended by a decrease in brightness. Since, however, it is more comfortable to view a larger image if sufficient illumination is present, in practice higher magnifying powers are commonly employed. Where the lighting permits, as much as twice the normal magnifying power can be used.

## 16. MAGNIFYING POWER

The magnifying power of the compound microscope is given by the product of the magnifying powers of the objective and the ocular. Since the image formed by the objective is examined directly by the ocular and not by the eye, the magnifying power of the objective may be considered to be simply the magnification between the object and the image. Applying equation (8) of Chap. 12, we may express the magnifying power  $M_o$  of the objective as

$$M_o = \frac{q - F_o}{F_o},$$

where  $F_o$  is the focal length of the objective and  $q - F_o$  is the distance of the image from its upper focal plane. The image formed by the objective is usually at the lower focal plane of the ocular. The corrections which are made in a microscope objective require that it be used at fixed image distance. The manufacturers usually specify that the distance from the upper focal plane of the objective to the lower focal plane of the ocular should be approximately 180 mm. Thus our equation becomes

$$M_o = \frac{180}{F_o}. \quad (11)$$

From equation (5), the magnifying power  $M_e$  of the ocular is

$$M_e = \frac{250}{F_e} \quad (12)$$

where  $F_e$  is expressed in millimeters.

For the complete instrument the magnifying power is given by:

$$M = M_o \times M_e = \frac{180}{F_o} \times \frac{250}{F_e} \quad (13)$$

The value of  $M_o$  is usually inscribed on the objective mount;  $M_e$  is found on the rim of the ocular. The magnifying power is simply the product of  $M_o$  and  $M_e$ . A 10X objective and a 10X eyepiece will give a magnifying power of 100X. A photomicrograph is usually designated as having a magnification of so many



“X,” e.g., “400X.” Unfortunately this designation of magnification by a product has the disadvantage at times of leaving the separate magnifications of objective and eyepiece in doubt; in addition it fails to specify photographic enlargement. We have seen that the objective is the determining factor in resolving power; the eyepiece produces further magnification without further resolving power. It is well, then, to make a notation on photographs of the magnification of both objective and eyepiece.

The magnification as determined above is at best a rough determination. For accurate work a determination should be made by means of a scale. There are several methods for doing this. We have seen earlier (Chap. 6) how this is done with a micrometer microscope. A filar micrometer eyepiece with a movable scale or cross hair can be obtained to adapt the ordinary microscope to micrometry. In conjunction with this eyepiece a stage micrometer scale should be used. This is simply a glass slide which is ruled in appropriate dimensions, such as 1 mm divided into 100 parts. Another and simpler means for micrometry is the ocular micrometer which has a scale fixed in its first focal plane. This scale will then be coplanar with the final image. It must of course be first calibrated by means of a stage micrometer.



Fig. 249. Greenough binocular microscope.

## 17. SLIDES AND COVER GLASSES

Microscopical objects which are to be mounted are immersed in an appropriate medium on a glass slide and then covered with a cover glass. The slide is usually 1 to 1.5 mm thick. For liquids of low surface tension slides with concave depressions are used. Cover glasses are available in three thicknesses: No. 1, approximately 0.15 mm; No. 2, 0.2 mm; and No. 3, 0.25 to 0.50 mm. Since the cover glass alters the length of the optical path, objectives are usually corrected for a specified cover glass thickness such as 0.17 to 0.18 mm. If a glass is used of greater thickness than that for which the objective is corrected, it is necessary to shorten the tube length; if the glass is too thin, the tube length must be increased. This correction can sometimes be made by means of a special collar on the objective. Failure to make this correction does not become serious except when short focal length objectives such as 4 or 3 mm are used. It should be noted, also, that in oil-immersion work the refractive index of the cover glass should be very close to that of the oil.



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# CHAPTER 39

## PHOTOMICROGRAPHY

What has been previously said concerning the photography of evidence is applicable with greater emphasis to photographs of microscopic findings. The practice of permitting an expert to testify concerning his microscopic observations without submitting photographs of the evidence is in many ways undesirable, particularly in a trial where there are two opposing experts. In a case of firearms identification, for example, the comparison of two shells in court can be most effectively and simply made by submitting a low-power photomicrograph to the jury and then discussing the points of similarity in the markings. Such an examination is a relatively simple matter, but the mere verbal testimony unaccompanied by photographs conveys little to judge or jury. In such cases, the jury usually passes judgment only on the personality of the expert and not on the merits of his testimony. In addition, where one expert's testimony is challenged by another, the presence of a photograph may offer a meeting ground for the dispute.

The permanence, too, of the photographic record has great value in microscopy because of the perishable nature of certain types of physical evidence. Semen examinations offer a good example of this class of evidence. As we have seen, a conclusive factor in such an examination is the identification of a spermatozoon under the microscope. If a photomicrograph is not made at the time of observation, the only record of the observation exists in the observer's memory and notes.

Finally, the objectivity of the photomicrograph contributes to the weight of such testimony. An example is offered by a narcotic case in which the nature of the drug is unknown. One of the critical tests distinguishing narcotics is the characteristic forms of the crystalline precipitates prepared with an alkaloidal reagent. Photomicrographs would be of assistance to the expert in court in defending his analysis.

There are, however, serious limitations to the objectivity of the photomicrograph. Interpretation of observations in high-power work is extremely important in microscopy. The manner in which the object is illuminated and observed can so greatly change its appearance that frequently only a person of



considerable experience can properly interpret the image. The significance of lights and shadows can be easily lost to the beginner, so that he may be led to interpret the outlines of the object to represent precisely the opposite of the true picture. The microscope is the optician's pinnacle of achievement, and should not be looked upon as a reading glass carried to its ultimate development.

## 1. THE CAMERA

For high-power work the camera consists essentially of a bellows and plate and is attached, without photographic lens, to the microscope. In low-power

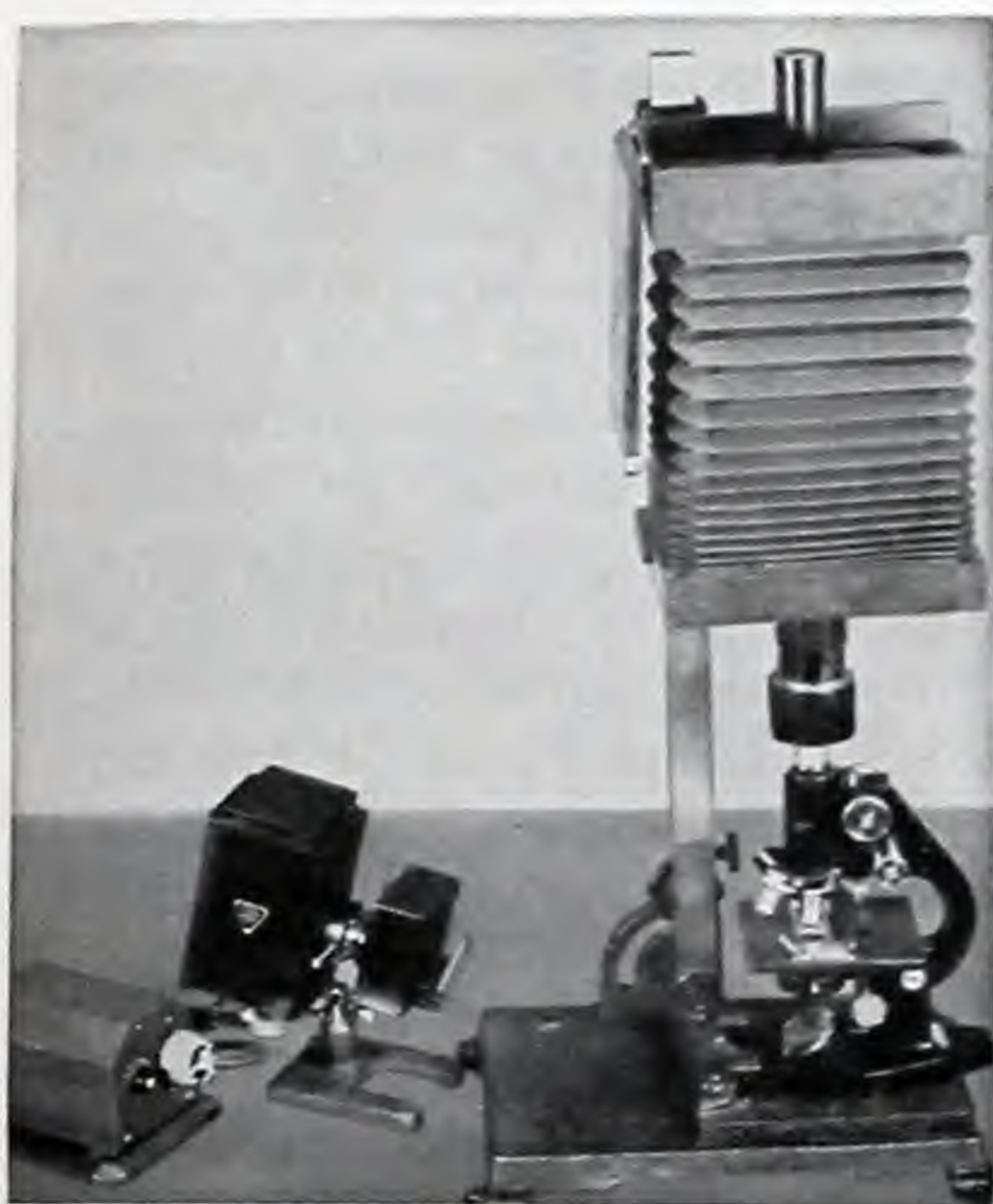


Fig. 250. Photomicrographic camera with adjustable bellows.



Fig. 251. Photomicrographic camera with fixed bellows.

photomicrography the microscope need not be used; instead, a photographic objective is used as a magnifier and is attached to the camera by means of a lens board in the usual position.

Two general types of camera may be mentioned: the adjustable bellows (Fig. 250) and the fixed bellows extension (Fig. 251). The former is preferable for critical work. It is ordinarily equipped with a scale to measure bellows extension for the calculation of magnification. The second type is usually attachable to the microscope. Strictly speaking, the bellows extension is not completely fixed since the distance of the ocular from the plate is variable. Some of these cameras are equipped with a viewing eyepiece and prism so that the field can be viewed until the exposure is made (Fig. 251). Among the cameras of the second type is the 35-mm camera such as the Leica<sup>1</sup> or Contax. Special attachments can



be obtained to hold the camera over the microscope (Fig. 252). This is another example of the wide applicability of the 35-mm type of camera in the work of criminalistics.

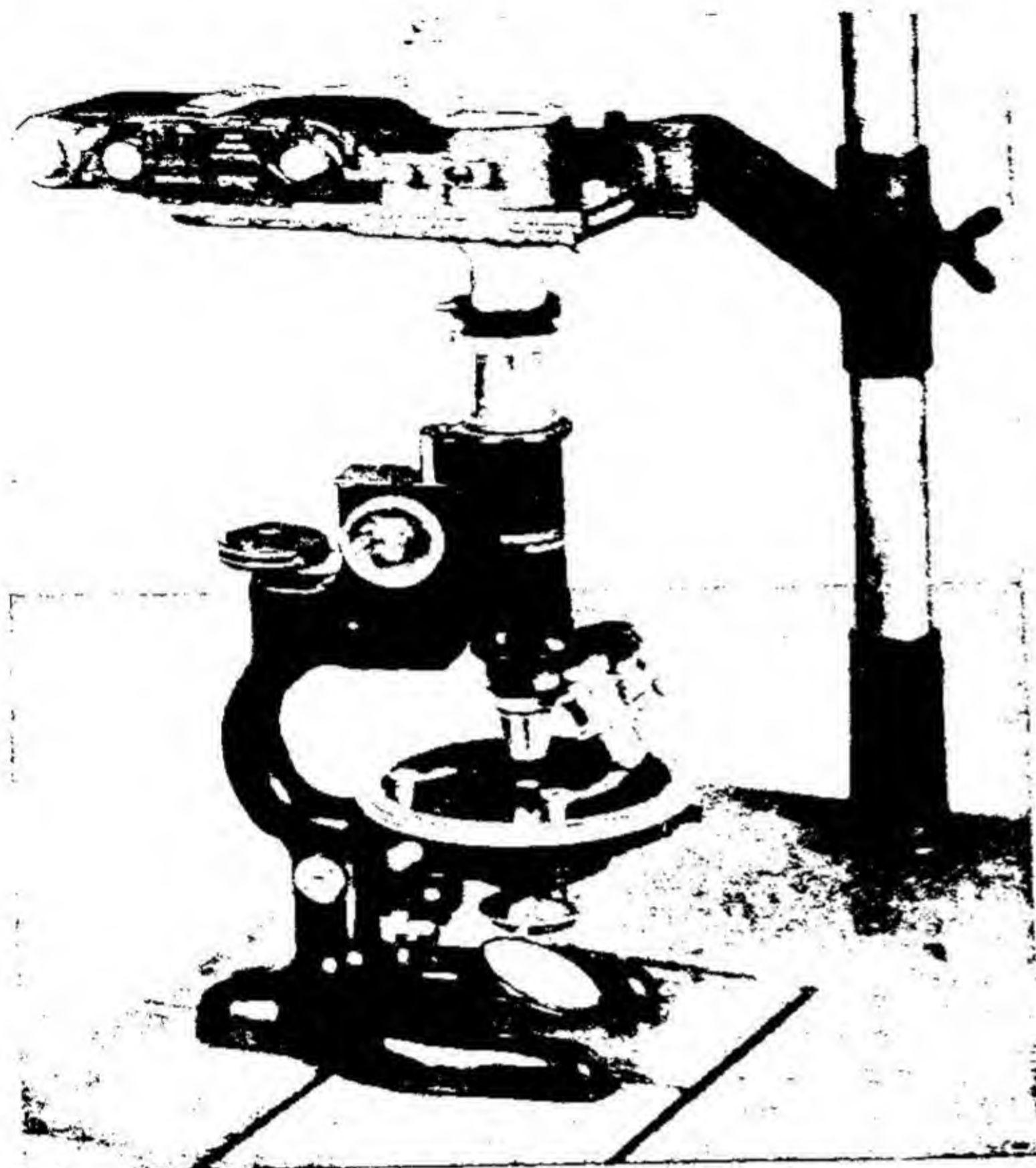


Fig. 252. Photomicrography with the 35 mm camera.

## 2. MAGNIFICATION

The concept of "normal magnifying power" is not applicable to photomicrography. Magnification can be determined by means of the following equation:

$$m' = \frac{Mx}{250} \quad (1)$$

where  $m'$  is the magnification of the photographic image with respect to the object;  $M$  is the magnifying power of the microscope as given by equation (13) of Chapter 38;  $x$  is the bellows extension of the camera in mm; and 250 is the distance in mm at which the image is seen when the microscope is used visually. The derivation of this equation can be seen from Fig.

253. If the ground glass is located in the plane  $AA'$ , 250 mm from the eyepiece, the magnification is the same as it would be for visual work. Extending the bellows a distance  $x$  from the eyepiece will result in an image at  $BB'$ . The magnification is now related to the previous magnification by the ratio  $\frac{BB'}{AA'}$ , which is the same as  $\frac{x}{250}$ .

## 3. PHOTOMICROGRAPHY WITH THE MICROSCOPE

For critical work the full microscope should be used. The camera is fitted over the eyepiece and the image is projected on the ground glass. Since in ordinary use the objective projects a real image in the first focal plane of the eyepiece, which then converts this image into a virtual image at a distance of 250 mm from the eye, it is necessary to alter the distance between the eyepiece and the objective in order that a real image can be formed by the eyepiece on the groundglass of the camera. This real image is obtained by having the image

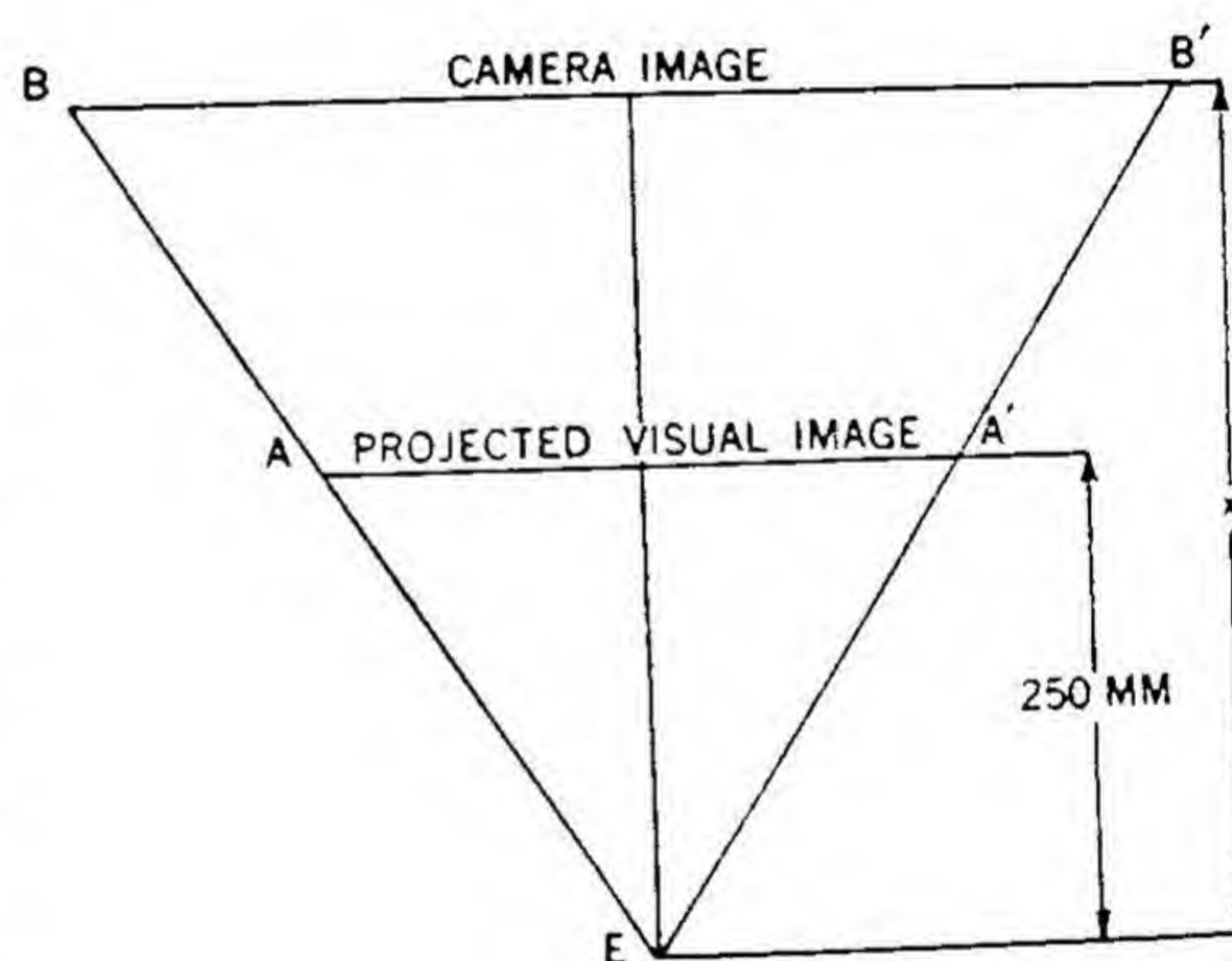


Fig. 253.



from the objective placed in front of the first focal plane of the eyepiece. To accomplish this a photo-eyepiece is used as the ocular. The real image should not be obtained by refocusing the objective, because the objective will then be in use at an image distance (and working distance) for which it is not corrected.

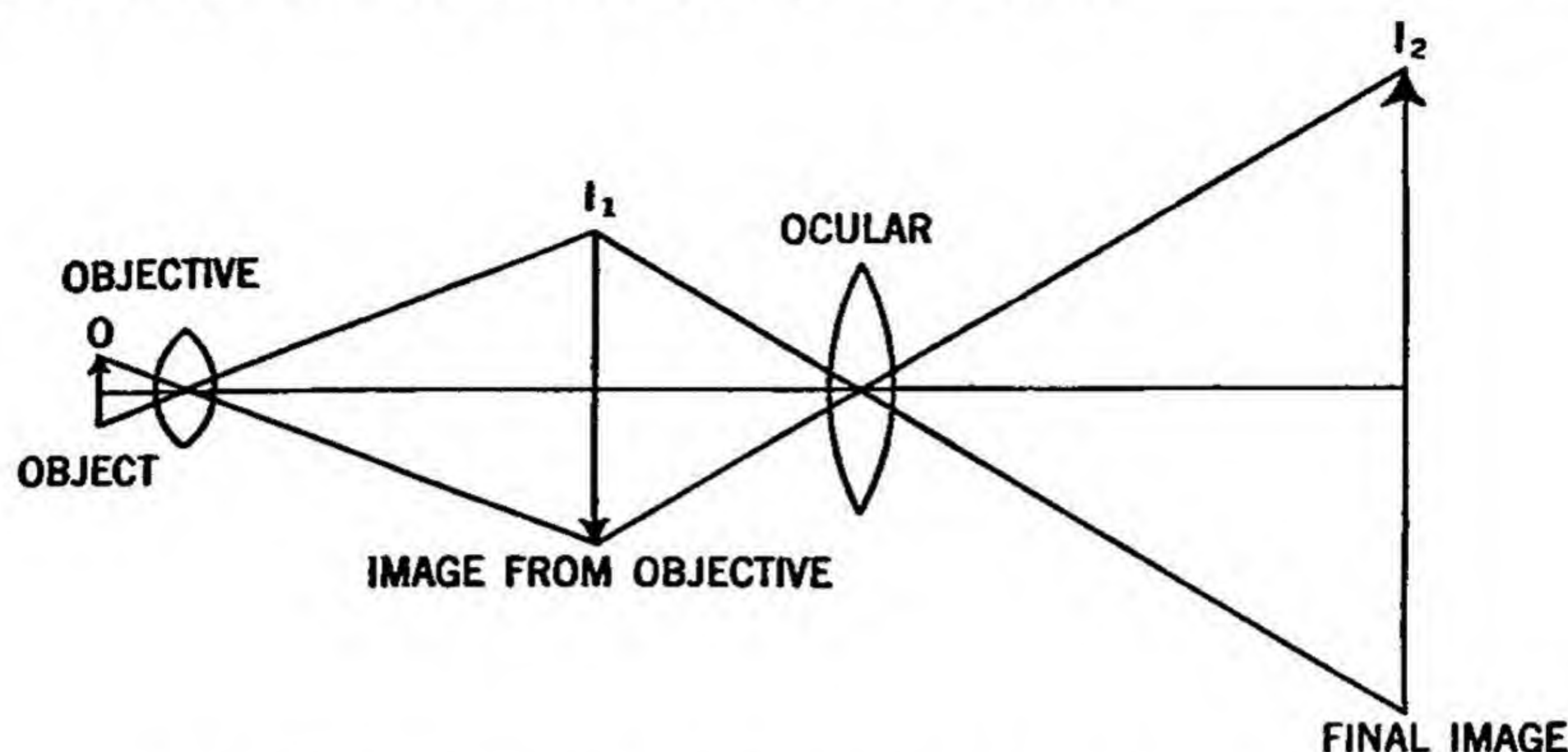


Fig. 254. Illustrating the formation of the image in photomicrography.

It is a good practice to determine magnification also by later photographing a stage micrometer with the apparatus in the same position.

#### 4. DEPTH OF FIELD

It has been previously stated that depth of field in photomicrography is considerably less than in visual microscopy. Since depth of field is inversely proportional to the square of numerical aperture, the employment of low magnifications offers one solution. Objectives equipped with iris diaphragms are another means of enhancing depth (at the expense of resolution). At low power a stereoscopic arrangement (binocular microscope, camera attachment, and print viewer) provides an excellent impression of depth. The problem of depth of field will be found to be more serious with opaque surfaces which are usually fairly uneven.

Since depth of field is greatly desired in photomicrographs that are to be used for court demonstration, it is recommended that unnecessary magnification by means of the objective be avoided. The needed resolving power should of course be attained. If it is then desired, for the purpose of comfortable viewing, to produce a larger photograph, the subsequent magnification can be achieved by projection printing.

#### 5. EXPOSURE<sup>2, 3, 4</sup>

Because of the possibility of vibration in the apparatus, exposures in photomicrography should be shortened as much as possible. Low magnification and strong illumination are the obvious aids to short exposures. Köhler illumination is used for this reason, in addition to its other advantages.

Exposure time in photomicrography is not readily predictable without considerable experience. The beginner should determine exposure time by means



of a test negative. The plate sheath is withdrawn partially and exposures made after successive partial withdrawals. The exposure times should form a geometric series. The range of exposure time in test negatives can be gradually diminished under the guidance of experience. Exposure data recorded for each negative will be found helpful.

## 6. PROCEDURE IN HIGH-POWER PHOTOMICROGRAPHY

Critical work in high-power photomicrography requires complete optical alignment of the various parts — camera, illuminant, and microscope elements. A photomicrographic arrangement is properly aligned when all of these parts have the same optical axis and the axis is normal to the negative at its center. If the microscope is upright, the axes are mutually perpendicular and centered. In the following procedure it is assumed that Köhler illumination is being used. A horizontal setup (Fig. 255) will be described. (The procedure for the vertical arrangement is the same except for the additional step of centering the image of the filament or arc to the mirror.) A bellows camera — 5 by 7 or 8 by 10 — is used. This should be equipped with an iris diaphragm or a disk with a pinhole at its center which can be placed over the opening for centering purposes. The camera and microscope are brought together by means of lighttight sleeve connectors. A dummy ocular with a pinhole at its center or similar arrangement is needed for centering the microscope.

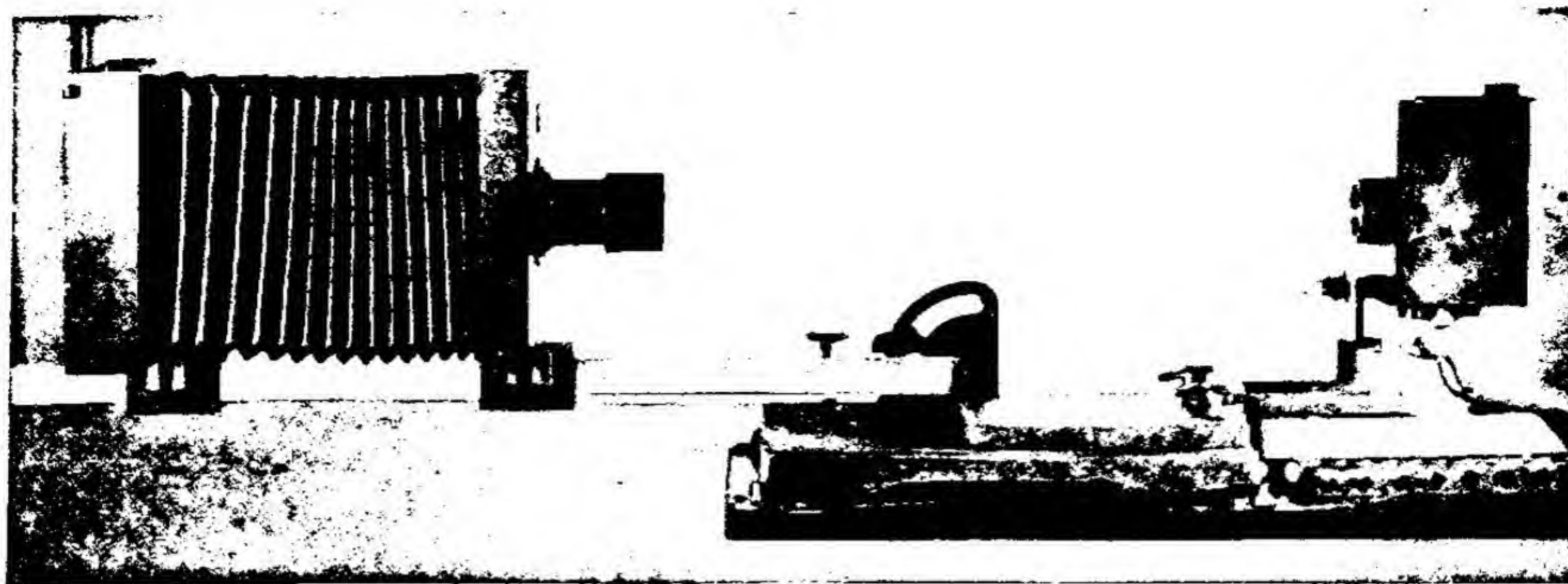
### Alignment

The optical axis of the whole photomicrographic arrangement is fixed by the axis of the camera — the line joining the pinhole opening of the iris diaphragm (or the disk) to the center of the negative. The axis of the other elements will now be aligned with this axis. With the bellows fully extended the iris diaphragm should be stopped down to the smallest opening (or the disk placed in position). To align the illuminant the elements — light condenser lens and light source (filament or arc) — must be aligned with respect to each other and then with the camera axis (the order of these steps is not fixed).

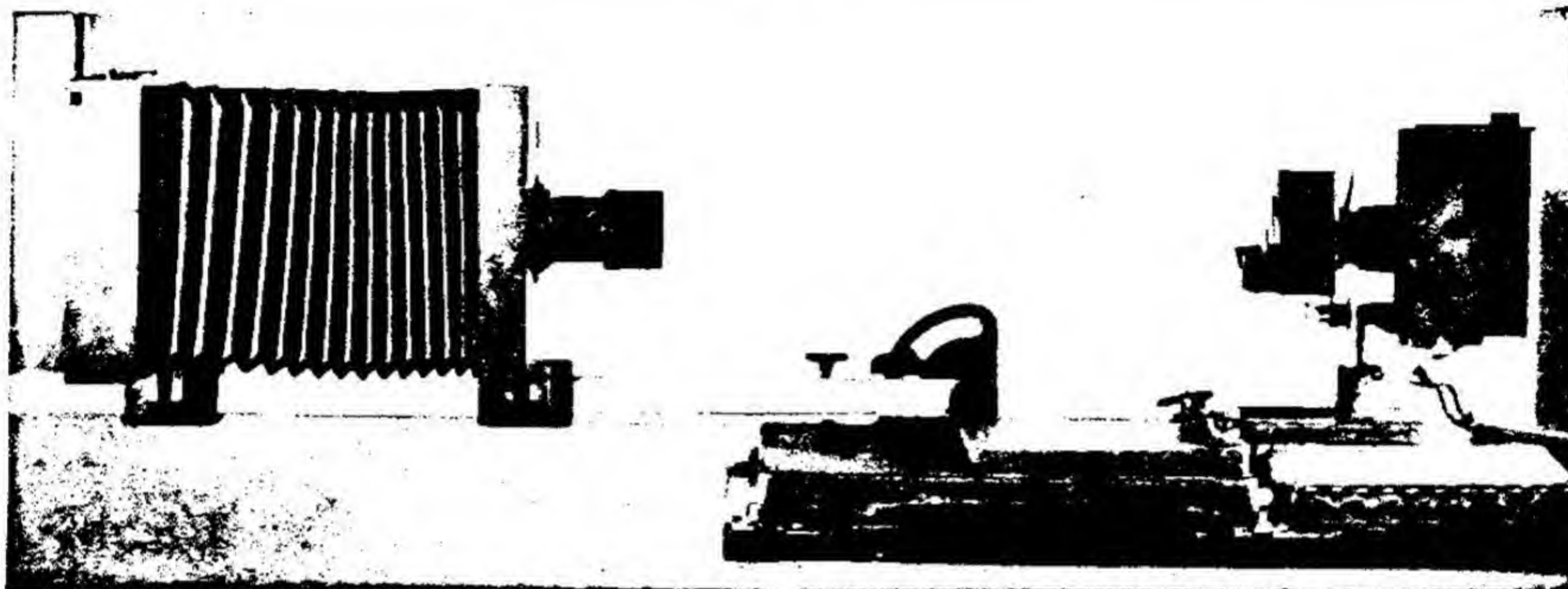
(1) Open the field diaphragm at the illuminant. (2) Remove the illuminant condenser lens (where possible) and arrange the light source by means of the centering adjustment so that a spot of light is seen in the center of the ground glass of the camera. (3) Replace the lens and adjust with respect to the light source until the spot is again seen at the center when the lens is focused. When the lens cannot be removed, the light source is centered with respect to the condenser and the whole adjusted until the light spot is seen on the center of the ground glass. The lamp distance should be such that when the microscope is in place the image of the source fills the front lens of the substage condenser.

The axis of the body tube of the microscope must now be aligned with the illuminant and camera. This axis is determined by the center of the ocular and the substage aperture diaphragm. Usually the latter of these is centerable. (1) With the microscope clamped in a stand remove the objective, condense

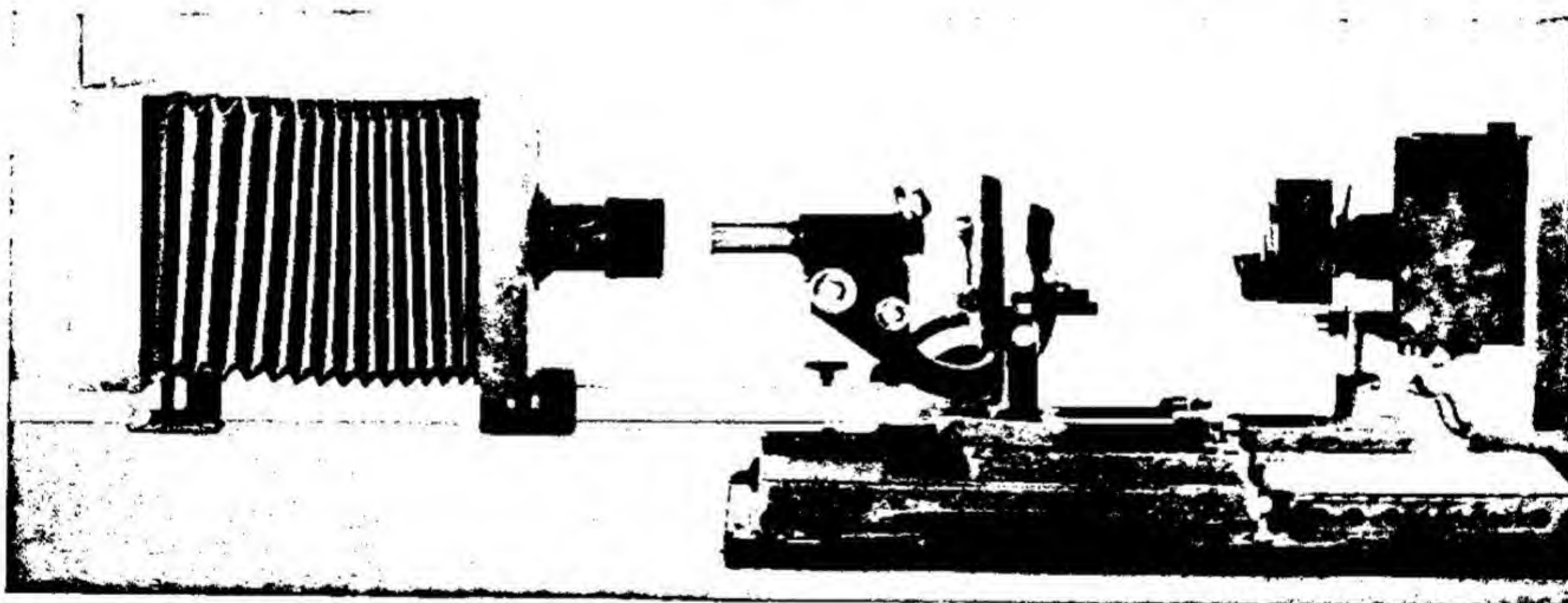




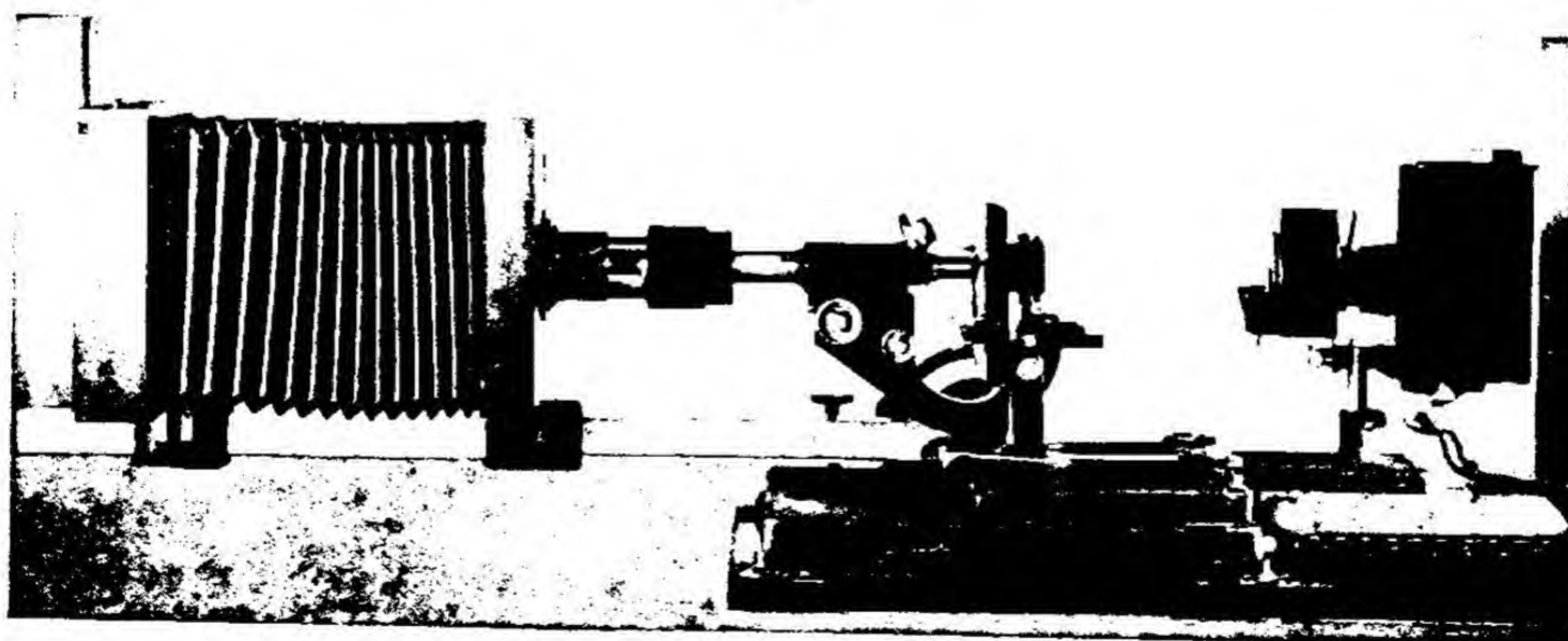
(a)



(b)



(c)



(d)

Fig. 255. (a) Aligning the optical axis of the camera with the lamp to form the optical axis of the system; (b) aligning the axis of the illuminant. The field diaphragm and the bull's-eye condenser have been placed on the lamp; (c) aligning the condenser and the objective (where possible); (d) aligning the body tube of the microscope. A pin-hole is used and the aperture diaphragm is set.



and ocular. Insert a dummy ocular with pinhole. (2) Center the aperture diaphragm with the respect to its mount and stop down to a small opening. The beam of light should still be seen at the center of the groundglass. Where this condition does not obtain, the microscope must be moved as a whole vertically or horizontally until the beam is centered. (3) With the camera diaphragm open and the microscope in a horizontal position adjust the microscope so that the sleeve connectors of camera and microscope can be telescoped when the lens board is moved toward the microscope. Now adjust the microscope until the spot of light is again seen at the center of the ground glass.

Either (or both) the substage condenser or the objective is centerable. The centerable element must now be aligned. (1) Rack back the front of camera and replace the pinhole ocular arrangement with a regular ocular. Place the objective, condenser, and object slide in position; partially open the substage aperture diaphragm, and focus the objective on the object. (2) Focus an image of the light source in the plane of the substage aperture diaphragm. (3) Partially stop down the field diaphragm and focus the substage condenser until the image of the diaphragm appears sharply in the field of view. (4) Center the image of the field diaphragm by centering either (or both, if possible) the substage condenser or the objective and repeat (2) and (3); open the field diaphragm until its image coincides with the desired field of view. The following final adjustments are then made: (1) Remove the ocular and adjust the aperture diaphragm until the back lens of objective is two-thirds filled with light. (2) Place a photo-eyepiece in the microscope and rack the front of camera forward until the sleeves are telescoped. Looking at the groundglass, focus the microscope critically. (3) By racking the back of the camera, limit the field of view as desired. (4) Looking at groundglass, focus the microscope critically. Examine the central clear area of the glass (or clear glass back) with a suitable magnifier for final focusing. If the magnifier has an adjustable focus, it should first be focused on the cross hair lines of the clear glass. (5) Insert the plateholder and after cessation of vibration expose the plate. Control of exposure may be had by means of a shutter or a light switch.

## 7. SUBJECTS IN PHOTOMICROGRAPHY

For the purposes of forensic work photomicrographical specimens may be classified into the following divisions:

- (a) Surfaces at low magnification
- (b) Fibers
- (c) Powders and particles
- (d) Metallographic and petrographic specimens at high magnification.

The latter three of these divisions comprise subjects which require extensive study and are treated in available textbooks. The first division is more specifically concerned with the problems of criminalistics. In certain cases a specially designed microscope, the *comparison microscope*, is necessary for the examination and comparison of this type of evidence.



### Surfaces at Low Power

A large part of laboratory microscopy will deal not with the identification of the nature of materials or with the analysis of extremely fine structure but rather with relatively gross comparisons of surfaces. Surface markings, texture, and workmanship will be examined to determine whether two specimens have a common origin. Among the specimens which will be encountered are the following: paper, textiles, leather, wire screens, surfaces bearing handwriting or type-writing, bullets in firearms identification, fractured metal parts (to show a fit), tool marks, deleted numbers which have been restored by etching, and paint films. Usually it is not necessary to employ filters in this type of photomicrography. However, with certain objects such as textiles or leather a color filter should be tried to improve the contrast. Cover glasses are avoided because of their tendency to contribute glare under these lighting conditions. Sometimes, to increase the apparent depth of field, the specimen is immersed in a mounting medium of higher refractive index.

Careful mounting of the specimen is important in obtaining a satisfactory picture. Textiles may be mounted by drawing them over a metal ring and fastening the ends by a rubber band or other means. Paper and leather may be made flat by means of cement or tacky tape at the corners. Small objects such as wire sections or bullets can be supported by means of small bits of modeling clay or bee's wax. The supports should not, of course, be visible in the field of view.

Photomicrographs of these specimens are usually made at 40X or less. A photographic objective of focal length greater than 16 mm is used. The 32-mm objective will have the most application in this work. In certain types of comparison work, such as that of handwriting, bullets, and tool marks, a comparison microscope is excellently suited for graphic illustration of the points at issue.

Over-stage illumination is usually employed in work of this nature. The major problem in lighting is to obtain a broad, uniformly illuminated field. For this purpose two or more lamps may be used, two usually being sufficient. The lamps are ordinarily separated by an angle of 90 degrees or more. The optimum angle is determined by examination of the groundglass. Similarly, the height of the lamps or angle of incidence of the illumination must also be chosen after experiment. In examining the groundglass the photographer should look for the following faults: unnecessary highlights or glare due to direct reflection of light into the lens from certain object areas; a flat field due to absence of any contrasting shadows; deep shadows which conceal important detail. The latter two errors are controlled by the placement of the lamps.

To eliminate unwanted highlights special care must be exercised to obtain a uniform field of illumination. A plane mirror can be placed in the field to test for glare. When the illuminants are not visible in the image of the mirror, the field is free from glare. In Fig. 256 a simple and effective scheme of illumination is shown. In addition to the usual microscope illuminants, bull's-eye lenses are used. An image of the lamp diaphragm (or of a diffusing plate placed near the



diaphragm) is formed in the object field by means of the bull's-eye lens. The area of the circle of light can be varied by changing the distance between the lamp and the bull's-eye lens (in addition to the usual iris diaphragm control). Changing this distance will alter also the intensity of the light.

The light from each lamp must be centered on the object field. Shillaber<sup>5</sup> describes a convenient method for doing this. A small white card serves as a test object. Three or four circles are drawn concentric with a black dot on the card.

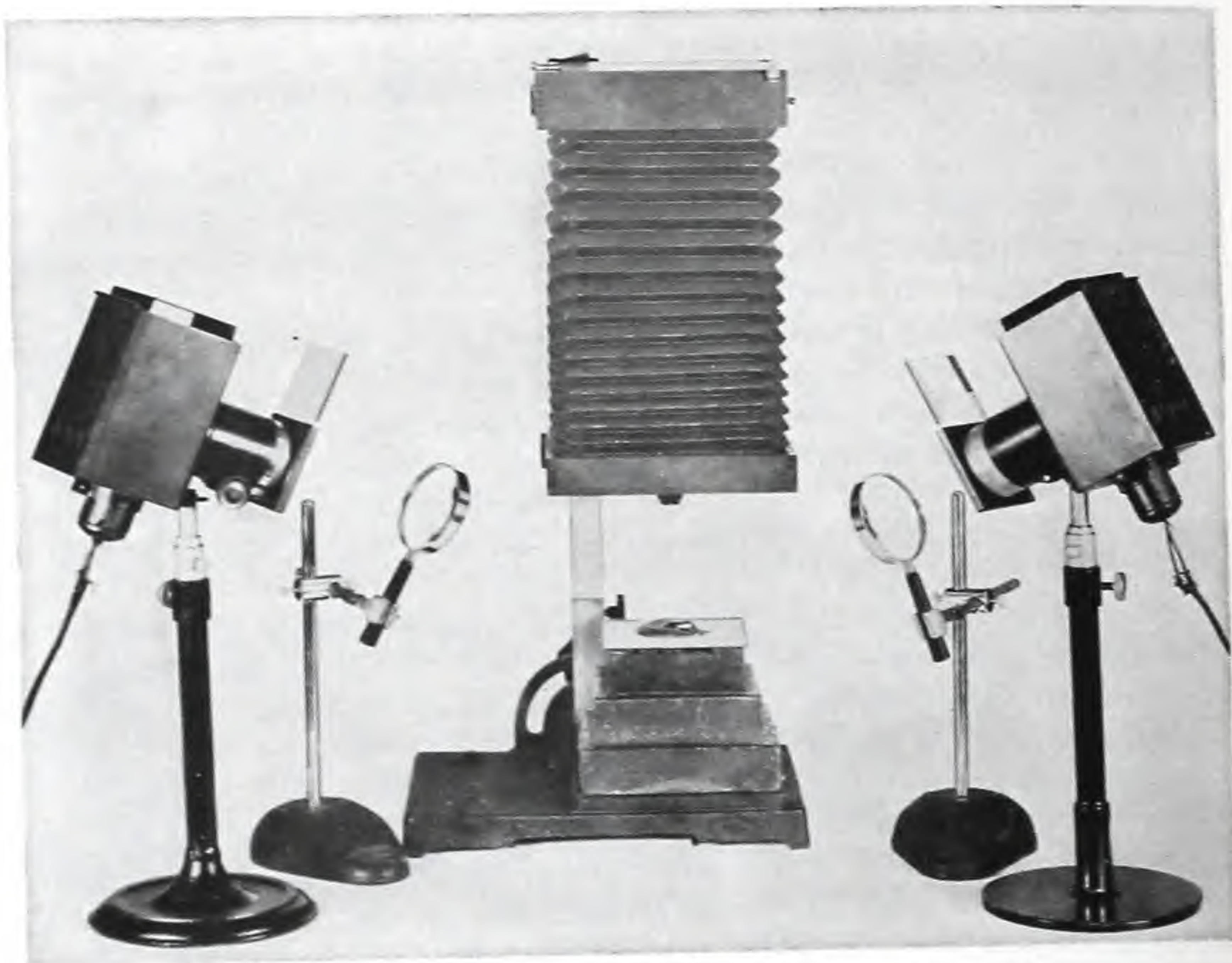


Fig. 256. An arrangement for low-power photomicrography.

The dot is then adjusted until its image lies in the center of the groundglass of the camera. Each light source is now centered separately. The lamp is first directed toward the target. If a diffusing plate is used, the lamp is adjusted for parallel rays. The bull's-eye lens is placed in the path and adjusted so that a spot of light is formed coincident with one of the target rings. The target is now replaced by the specimen so that the plane of greatest interest is at the same level as that which the target occupied.

### The Comparison Microscope

This instrument is ideally suited to the work of a police laboratory. Many forensic problems involve a direct microscopic comparison at low power. In tool



mark cases and bullet comparisons, for example, it is necessary to match a number of fine lines in the evidence sample and the standard. To do this with a degree of ease it is necessary to have each specimen on a separate microscope stage. In the comparison microscope two stages and two objectives are used (Figs. 257 and 258). By means of prisms the images from the objectives can be observed through a single ocular. The images appear in one field, separated by a fine line. Fig. 259 shows the optical paths in one type of comparison microscope.

The following general procedure will be found applicable to most comparison microscopes, particularly the one shown in Fig. 257:

- (1) Focus the ocular on the dividing line.
- (2) Adjust the specimens in the approximate positions which they will occupy in the photograph.
- (3) Focus one of the specimens by manipulating the stage until parallax is

eliminated; i.e., when the eye is moved across the ocular there should be no relative motion between the object and the dividing line. If motion is observed this indicates that the image of the object is not in the plane of the dividing line.

(4) Repeat this procedure with the other specimen.

(5) Adjust the specimens so that the lines are matched and properly centered in the field. Refocusing may be necessary after this step.

(6) Lower the camera over the microscope leaving adequate space for the ocular to move upwards.

(7) Observing the field through a magnifier on the clear area of the groundglass back, turn the ocular upward until the dividing line is in

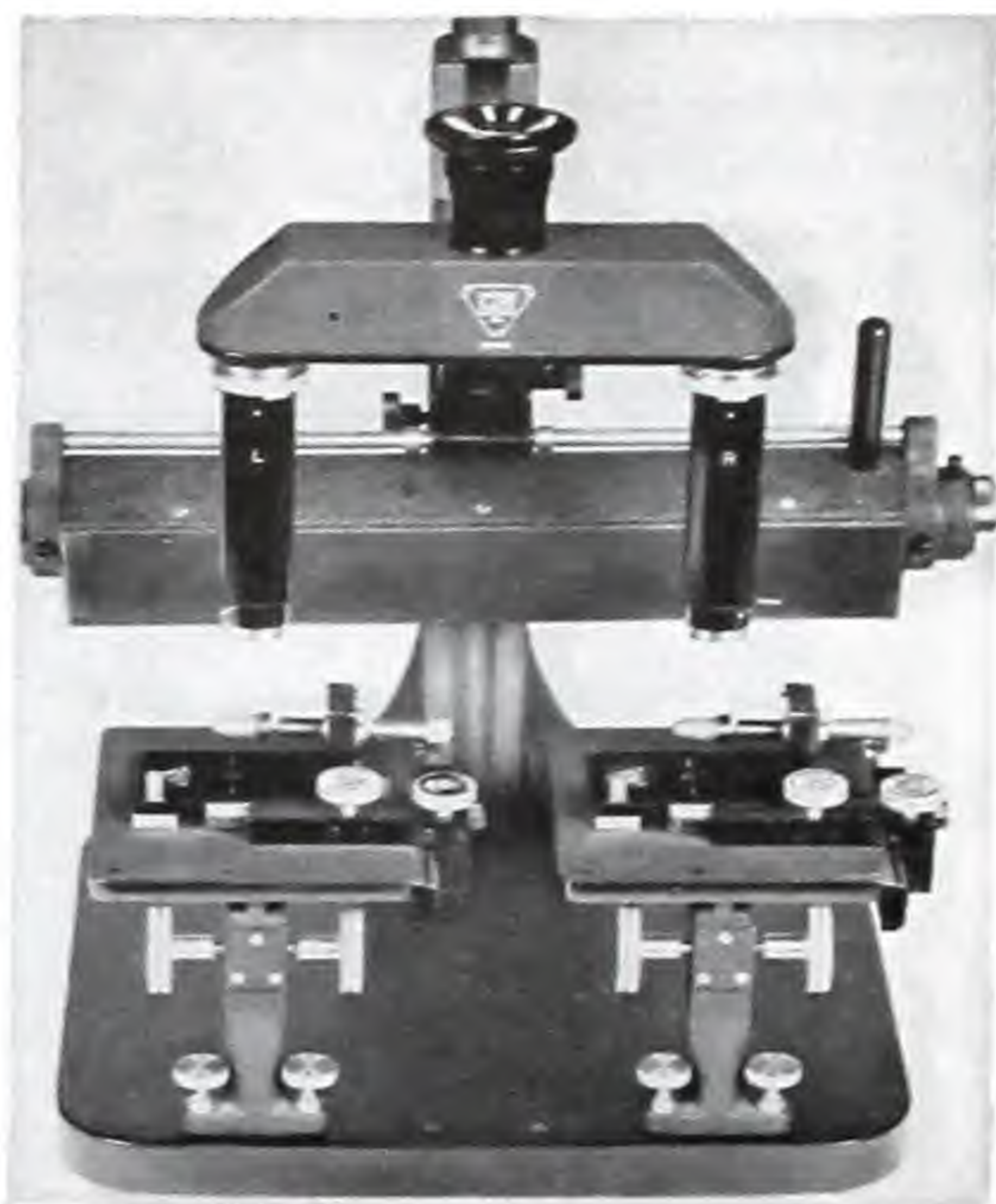


Fig. 257. The comparison microscope.

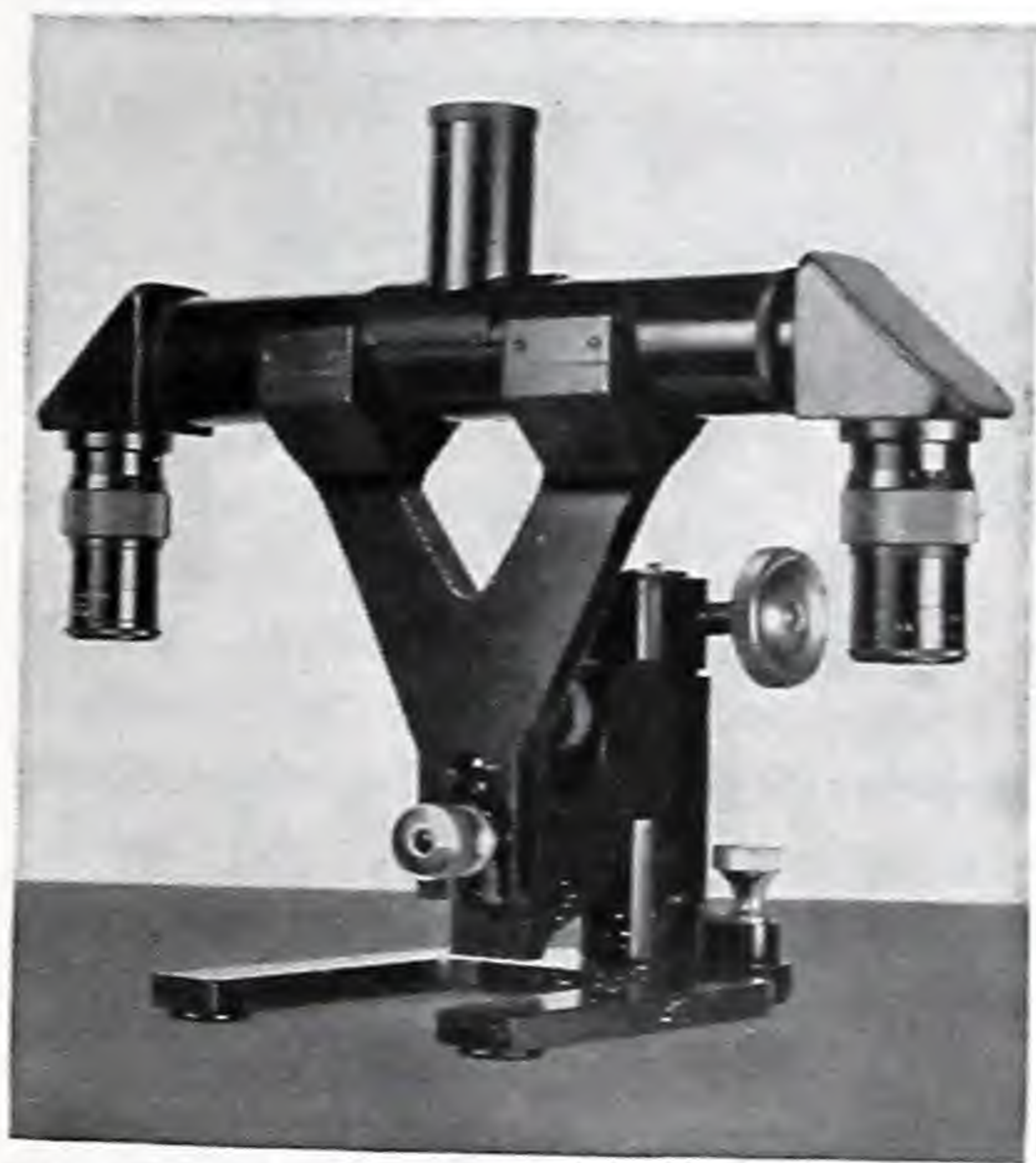


Fig. 258. Another type of comparison microscope.



sharp focus. If all the steps have been performed correctly, images of the specimens should now be in correct focus without parallax and equally magnified. If this condition is not achieved the whole procedure should be repeated.

There are two common errors. First is failure to focus the ocular correctly on the dividing line in step (1) above. This results in the dividing line not being in focus on the groundglass when the rest of the field is in focus. The operator should determine by experiment the position of the ocular for which the dividing line is in correct focus. The experiment would consist in following the complete procedure described in the preceding paragraph until perfect focus is simul-

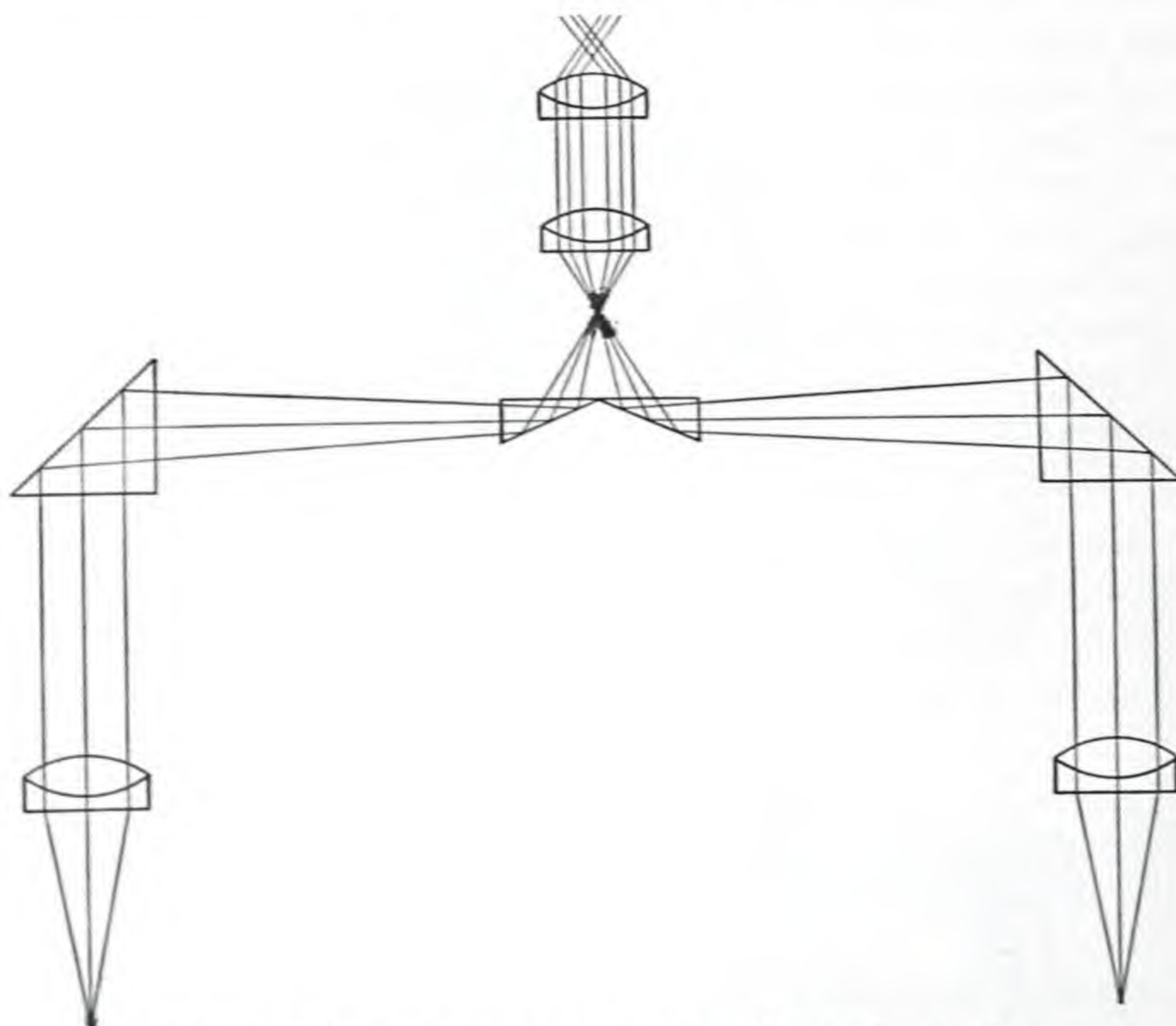


Fig. 259. Optical paths in a comparison microscope.

taneously obtained for the field and the dividing line. The position of the ocular in step (1) may then be marked by a small scratch on the collar of the ocular.

A second error lies in failure to focus correctly in steps (3) and (4). Unless the specimens are carefully focused, their images will be at different magnifications, and corresponding markings will not be perfectly aligned. In addition, the dividing line and the specimens will not be in focus on the groundglass for the same position of the ocular. To avoid this error critical judgment should be exercised in determining the position of correct focus. The test for parallax should be employed frequently while focusing.

The illumination of specimens for photomicrography with this microscope presents a problem because of the number of lamps required. The illuminants attached to the microscope are adequate for visual work but not for photography.



With many subjects it is desirable to employ the method of illumination described above for low power. This, however, would entail the use of two pairs of similar lamps and four bull's-eye condensers. Such equipment is not ordinarily available to the microscopist. One solution is to employ two lamps and con-



**Fig. 260.** A comparison of two bullets by means of the comparison microscope. Note the sharp dividing line (running horizontally) in the center of the photograph.

densers, and to photograph each half of the field separately. The lamps are moved between exposures and arranged in the corresponding position for the second specimen. For bullet comparisons (Fig. 260) and other work where the direction of the lighting with respect to the field is important, a single lamp and condenser can be used for each specimen. Small white cards may be used with bullets to illuminate the side of the bullet opposite the lamp.

#### **Fibers**<sup>6, 7, 8, 9, 10, 11</sup>

Fibers and hairs are frequently encountered as traces at the scene of the crime. The following are some of the more common fibers: cotton, wool, rayon.



nylon, paper, hair, fur, and feathers. A magnification of 200X to 400X is usually employed. Ordinarily the illumination is that of transmitted light, but over-stage lighting is sometimes used (in hair examinations, for example) to examine surface structure.

The specimen is photographed longitudinally or in cross section. When viewed longitudinally it is usually necessary to make the fiber transparent. Bleaching may be required where the fiber is not naturally transparent or is dyed. A suitable mounting medium is used. Hair and deeply dyed textiles, for example, are mounted in a liquid of refractive index of approximately 1.55.

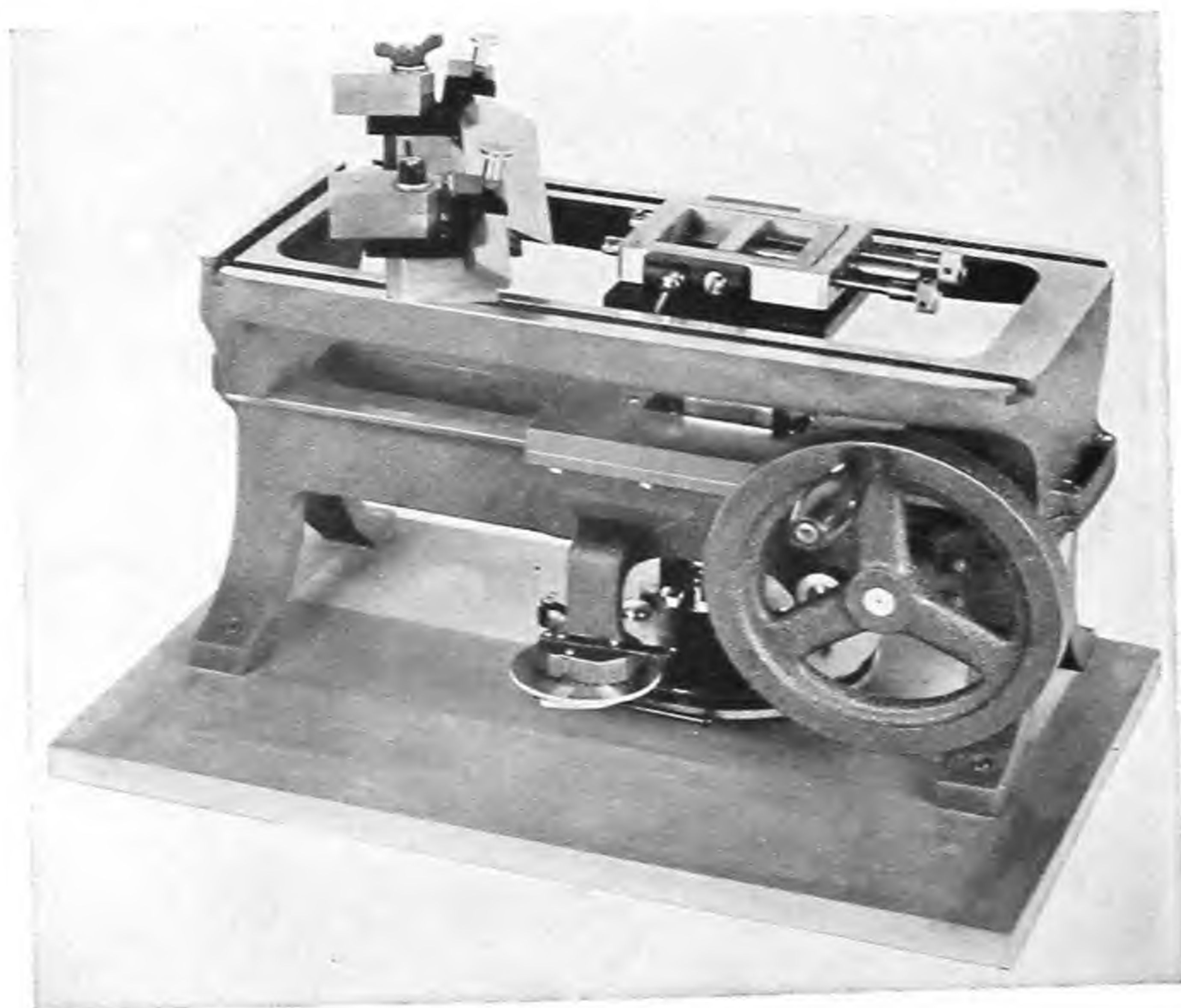


Fig. 261. A microtome.

The cross-sectional surface is of great importance in the case of hair, where it may serve as a means of distinguishing human from animal hair. In sectioning the fiber the aim is to cut without shearing or tearing since the shape of the surface is significant. In general, wherever it is necessary to study plant or animal tissues a cross-sectioning device is indispensable. Such an instrument is called a *microtome*. It may be of the elaborate type such as that illustrated in Fig. 261 or a simple instrument such as the Hardy microtome, which is quite effective in cross-sectioning fibers. A relatively complex technique is required for the proper use of the microtome.

### **Powders and Particles**<sup>12, 13, 14, 15, 16, 17, 18, 19, 20, 21</sup>

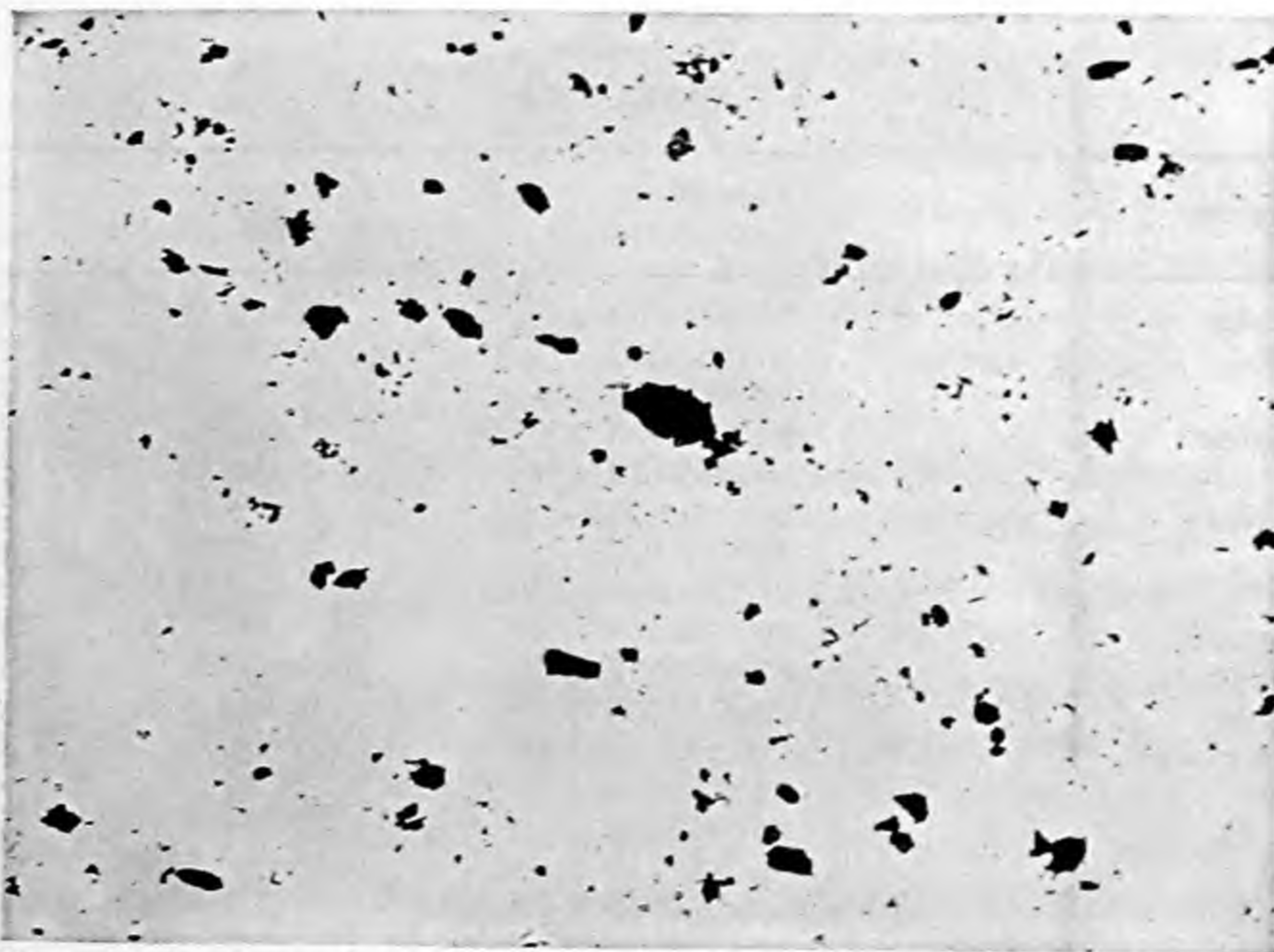
This division includes materials which, under the microscope, present a field of discrete entities such as particles or cells. The subjects of most frequent occur-



rence in forensic microscopy are gunpowder, cosmetics, narcotics, drugs, sugar, starch, abrasives, soil, paints, blood and other bacterial smears. Magnifications of 100X to 500X may be required. The illumination is ordinarily substage — bright-field or dark-field. Mounting media and stains are usually employed. In fact, the complete resources of the experienced microscopist are required in work of this nature. The reader is referred to the references listed above for specialized methods.

### **Metallographic and Petrographic Specimens**<sup>22, 23, 24, 25, 26, 27</sup>

This class includes opaque specimens which are examined at relatively high magnifications. Vertical illumination is used. Where special equipment is not available the biological microscope may be used with a vertical illuminator.



**Fig. 262. A photomicrograph of coal dust found in a suspect's trouser cuff.**

Specially designed microscopes are available for this work — the metallographic microscope for metal specimens which are polished and etched, and the petrographic microscope for polished ore specimens.

Metal specimens are examined microscopically in cases of identification and comparison. It is, however, in cases of accidents and sabotage that elaborate metallographic technique is required. Failure of chains, clamps, and other metal equipment under load may be due to defective material or tampering. An examination of the cross-sectional surface will reveal defects due to the treatment of the metal.

The preparation of metallic and petrographic specimens requires special equipment for mounting, grinding, and polishing. A molding press and a lap are necessary. The polished metallic specimen must also be etched.



**Stains**<sup>28, 29, 30, 31</sup>

The use of stains is an indispensable part of the technique of the microscopist especially when dealing with biological subjects. The purpose of staining is to increase the contrast between various parts of a specimen and also to increase visibility in the same manner as a mounting medium. Some elements in a specimen will absorb a stain to a greater degree than others. It is possible to stain different elements of the same specimen with different dyes. Thus, if there are two kinds of fibers present, it may be possible to distinguish one from the other by means of two different stains. Methylene blue, Herzberg's stain, Lugol's solution are some of the stains of wide applicability.

Table 24 lists some of the more common biological stains. (The table is explained below under "Filters.")

**TABLE 24**

STAIN	SPECTRAL ABSORPTION	RECOMMENDED WRATTEN FILTER	SPECTRAL REGION USED
Acid fuchsine	5300-5600	B and G	5100-6000
Aniline blue	5500-6200	B and E	5600-6000
Azure I	5800-6400	B and E	5600-6000
Basic fuchsine	5200-5500	B and G	5100-6000
Carmine	5000-5700	B and G	5100-6000
Crystal violet	5500-6100	B and G	5100-6000
Eosine Y	4900-5300	B and H	4800-5400
Hematoxylin (Ehrlich)	Gradual through green	B and G	5100-6000
Light green SF	6000-6600	F	6100-6800
Methyl green	6200-6500	F	6100-6800
Methyl violet	5500-6000	B and E	5600-6000
Methylene blue	6000-6200 and 6500-6800	A	5900-7000
Orange II	4600-5100	C	4000-5100
Safranin O	4800-5400	G and H	5100-5400
Sudan III	General in blue and green with maximum at 5000	G and H	5100-5400
Sudan IV		G and H	5100-5400

**8. MOUNTING MEDIA**<sup>32, 33</sup>

In photomicrography at medium and high powers it is usually necessary to mount the specimen in a suitable medium. Air or dry mounts are frequently used, but liquid media are more common. The mounting medium serves several purposes. By selecting a medium of appropriate refractive index, the contrast between the medium and its background can be effected. When the refractive index of the medium is close to that of the specimen the latter becomes more transparent. When the two indices differ widely great contrast is obtained. The choice of a mounting medium must be guided by experience and by the recommendations which are to be found in the literature for various classes of specimens. Some of the more commonly used media are listed in Table 25.



**TABLE 25. Common Mounting Media**

MEDIUM	REFRACTIVE INDEX
*Water	1.33
Glycerin	1.46
*Nujol	1.47
Dammar	1.52
Canada balsam	1.54
*Bromoform	1.57
Styrax	1.57-1.60
*Bromonaphthalene	1.66
Styrene resin	1.66
*Methylene iodide	1.74

\* These are useful only for temporary mounts

## 9. FILTERS\* 34, 35, 36

We may classify filters in photomicrography according to their function. Neutral filters, which absorb uniformly in all wave lengths, are used to control the intensity of the light; color filters control contrast and assist in the color corrections provided by the optics of a microscope; heat-absorbing filters are used to protect the microscope and the specimen from the intense heat given by powerful light sources such as arc lamps.

Filters are ordinarily placed between the lamp and the microscope. Neutral filters which have a ground glass surface are used as diffusing plates and are placed close to the lamp in order that they may serve as a secondary light source.

The selection of filters for contrast must be guided mainly by experience. A few general principles can be given. Blue filters aid in resolving very small particles, because of the shorter wave length of the light transmitted. A green filter such as Wratten No. 62 or Corning No. 401 is used extensively, especially in photomicrography of metals. Information concerning the filters which are particularly helpful in special branches of microscopy can be obtained from the literature. As a general guide, when contrast is required, Table 26 may be used.

**TABLE 26**

COLOR OF STAIN	COLOR OF FILTER
Blue	Red
Green	Red
Red	Green
Yellow	Blue
Brown	Blue
Purple	Green
Violet	Yellow

In Chapter 15 the characteristics of the commonly used filters are given. These filters can be used in combination, as described there, in order to limit

\* See Chap. 15.



the light to a narrow spectral region. The advantage of using a narrow transmission band lies in improved definition as well as contrast. As we have seen, microscopic objectives are corrected for only certain wave lengths; hence the employment of approximately monochromatic light leads to better focus.

Table 27 lists some of the more commonly used filters.

TABLE 27

WRATTEN NUMBER	NAME	VISUAL COLOR	SPECTRAL REGION TRANSMITTED
25	A	Orange-red	From 5900 to red end
58	B	Green	From 4800 to 6200
47	C5	Blue-violet	From 3700 to 5100
35	D	Purple	From 3200 to 4700 and from 6500 to red end
22	E	Orange	From 5500 to red end
29	F	Red	From 6100 to red end
15	G	Yellow	From 5100 to red end
45	H	Blue	From 4300 to 5400
11	X1	Pale green	For orthochromatic reproduction with tungsten light

These filters can be used in combination in order to achieve a narrower region of spectral transmission. The resulting colors and dominant wave lengths are given in Table 28.

TABLE 28

FILTERS	DOMINANT WAVE LENGTH	COLOR
D and H	4450	Violet
C and H	4600	Blue
B and H	5100	Bluish-green
G and H	5250	Pure green
B and G	5400	Yellowish-green
B and E	5750	Greenish-yellow
A	6000	Orange-red
F	6250	Red
A and D	6700	Deep red

In Table 24 the absorption bands of the more common stains are given. The filters are chosen to give the maximum contrast; i.e., the filter chosen transmits in the region absorbed by the stain. For example, basic fuchsin absorbs in the region from 5200 to 5500; the combination of a B and G filter transmits from 5100 to 6200. The spectral region used is approximately 5100 to 6000. The dominant wave length is 5400.

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# CHAPTER 40

## MEASUREMENT OF REFRACTIVE INDEX

### 1. GENERAL

Because of the great accuracy with which it can be made, measurement of refractive index can be used as a means of identifying a substance. It serves also as a means of quantitative analysis of solutions and as a test for the purity of a substance, and provides an excellent method of detecting differences in the compositions of small samples of related compounds. In the work of criminalistics refractive index is an important property for dealing with samples of clue materials because the techniques involved in its measurement do not require the destruction of the sample and are effective in working with small quantities. The sample on which the measurements are made can be preserved for presentation as evidence in court and for further tests if a check is required. The most common use of refractive index measurements is in the comparison of small glass particles found in connection with a hit-and-run case. In crimes of assault and burglary, fragments of glass found on the suspects' clothes are compared with pieces found at the scene.

The refractive index  $n$  of an isotropic medium is defined as the ratio of the velocity of light in air  $v_a$  to its velocity in the medium  $v_x$ ; i.e.,  $n = v_a/v_x$ . For solids and liquids the refractive index given in the tables of data is ordinarily referred to air at 20 C or to the conditions of temperature and pressure under which the measurement was made. Usually it is not necessary to correct results to standard pressure and temperature conditions, since the correction is of the order of magnitude of  $1 \times 10^{-5}$ .

### Effect of Temperature

There is a small variation of refractive index with temperature which becomes of considerable importance when fourth or fifth place accuracy is essential. The value of  $dn/dt$  for solids is much smaller than for liquids. It may be positive or negative for solids and is usually negative for liquids except in the vicinity of the boiling point. For many organic liquids  $dn/dt$  has a value of approximately  $-4.5 \times 10^{-4}$ .



To obtain accuracy in the third decimal place of  $n$  for liquids, a temperature control within 2 C is necessary. In the fourth decimal place, a control within 0.2 C is necessary, and for fifth place accuracy, in addition to finer temperature control (within 0.1 C), the atmospheric pressure should be specified. A superscript is used to indicate the temperature at which the index is measured. Thus,  $n^{20}$  is the refractive index at 20 C.

### Effect of Wave Length<sup>1</sup>

The change of refractive index with the wave length,  $dn/d\lambda$ , of the light used in the measurement is of great importance. A subscript is used to indicate this wave length; thus  $n_D$  indicates that the measurement is referred to the sodium *D* line (5893A). Electric discharge tubes of various types are used as light sources with refractive index instruments. The one most commonly employed is the sodium lamp which gives a very intense sodium doublet. For dispersion measurements the mercury lamp is used. This lamp gives four intense lines between the yellow and the violet. Where special lamps are not available, a tungsten lamp can be used with an appropriate filter such as the Wratten 64, Wratten 73, or a combination of two Corning filters — Corning 428 and 348A.

## 2. CRITICAL ANGLE METHODS<sup>2</sup>

If  $n_x$  and  $n_p$  are the respective refractive indices of the medium in question and the prism, then from Snell's law we have

$$n_x \sin i = n_p \sin r \quad (1)$$

where  $i$  is the angle of incidence and  $r$  the angle of refraction of any ray passing into the prism from the medium. In the limiting case where the incident ray just grazes the face of the prism (Fig. 263), the angle of refraction is the critical angle. No ray can emerge above the critical ray within the prism because such rays cannot enter the prism. Considering the rays within the prism as traveling in the opposite direction, we can see that rays striking at an angle greater than the critical angle will be internally reflected. Since  $i = 90$ , equation (1) becomes

$$n_x = n_p \sin \alpha, \quad (2)$$

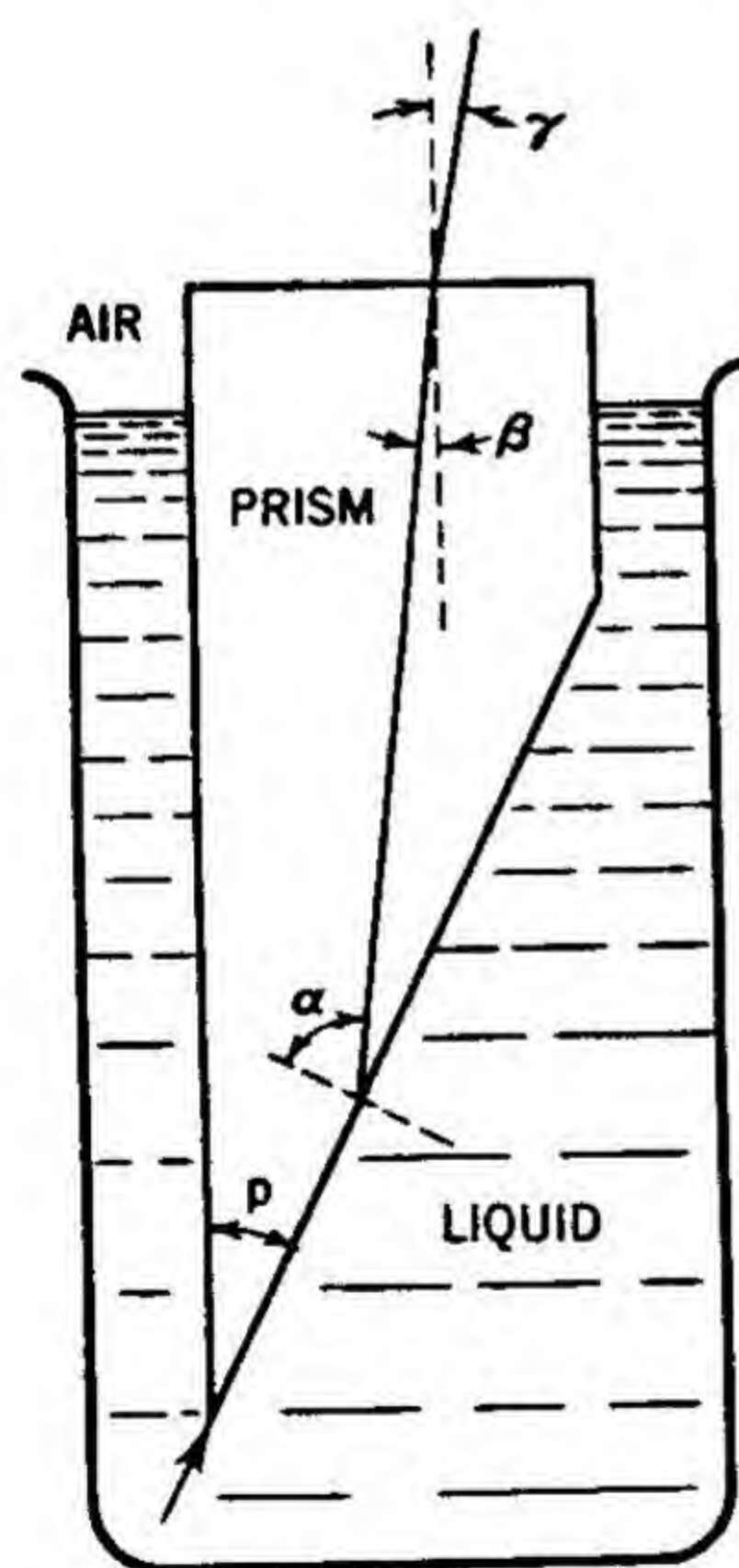
where  $\alpha$  is the critical angle.

Since  $n$  for air is unity, we have at the upper face of the prism

$$n_p = \frac{\sin \gamma}{\sin \beta} \quad (3)$$

Fig. 263. Illustrating the principle of the refractometer.

By means of equation (3),  $\alpha$  can be expressed in terms of  $\gamma$ . The index of refraction is then determined by measuring  $\gamma$ . This is the principle of the refractometer.





Referring again to Fig. 263,

$$\alpha = \beta + 90 - p,$$

where  $p$  is the angle of the prism; and

$$\sin \alpha = \sin (\beta + 90 - p)$$

or

$$\sin \alpha = \sin \beta \sin p + \sqrt{1 - \sin^2 \beta} \cos p.$$

But

$$\sin \beta = \frac{\sin \gamma}{n_p};$$

hence,

$$n_p \sin \alpha = \sin \gamma \sin p + \sqrt{n_p^2 - \sin^2 \gamma} \cos p.$$

From equation (2)

$$n_x = \sin \gamma \sin p + \sqrt{n_p^2 - \sin^2 \gamma} \cos p.$$

Since  $p$  and  $n_p$  are constants,  $n_x$  is a function of  $\gamma$  alone.

A refractometer based on the critical angle principle is equipped with telescope which is focused on the upper face of the prism. On looking into the telescope, the observer sees the field divided into a bright area and a dark area. The position of the boundary line is determined by the critical ray, i.e., by the value of  $\gamma$ . The refractive index is read either directly or from a table interpreting scale readings. The most common types of refractometers are the Pulfrich, the Abbé, and the dipping refractometer. The latter two are described below. For an appreciation of the sources of error in refractometry the reader is referred to the work of Tilton.<sup>3</sup>

### The Dipping Refractometer<sup>4, 5, 6</sup>

This is an excellent instrument (Fig. 264) for measuring the refractive indices of liquids within a range of about 1.3 to 1.7. Figure 265 illustrates the optical system, which is essentially that of a telescope. The prism is immersed in a small beaker of liquid. Rays from the mirror pass through the prism, the critical ray marking the border between the light and dark parts of the field of view. A micrometer eyepiece and vernier are used to accurately determine the achromatized dark border. A table is provided by the manufacturers for convert-

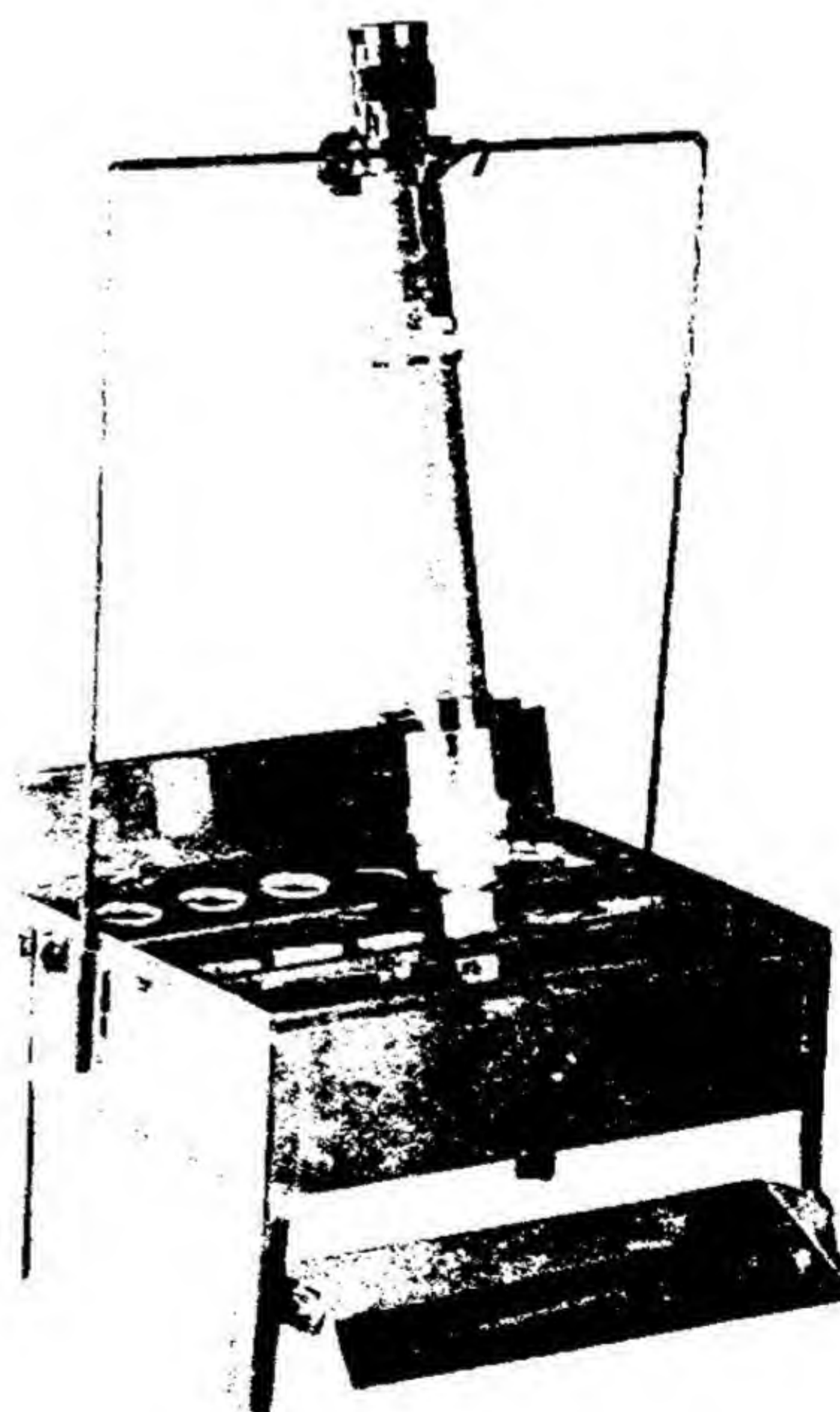


Fig. 264. The dipping refractometer.



ing the arbitrary scale readings into refractive index readings after a zero correction has been made. The instrument suffers from several minor disadvantages — difficulty of temperature control, limited range of  $n$ , exposure of the sample, and that it gives only semiquantitative dispersion measurements. The accuracy of the instrument, however, is very great, approaching  $\pm 0.00003$ .

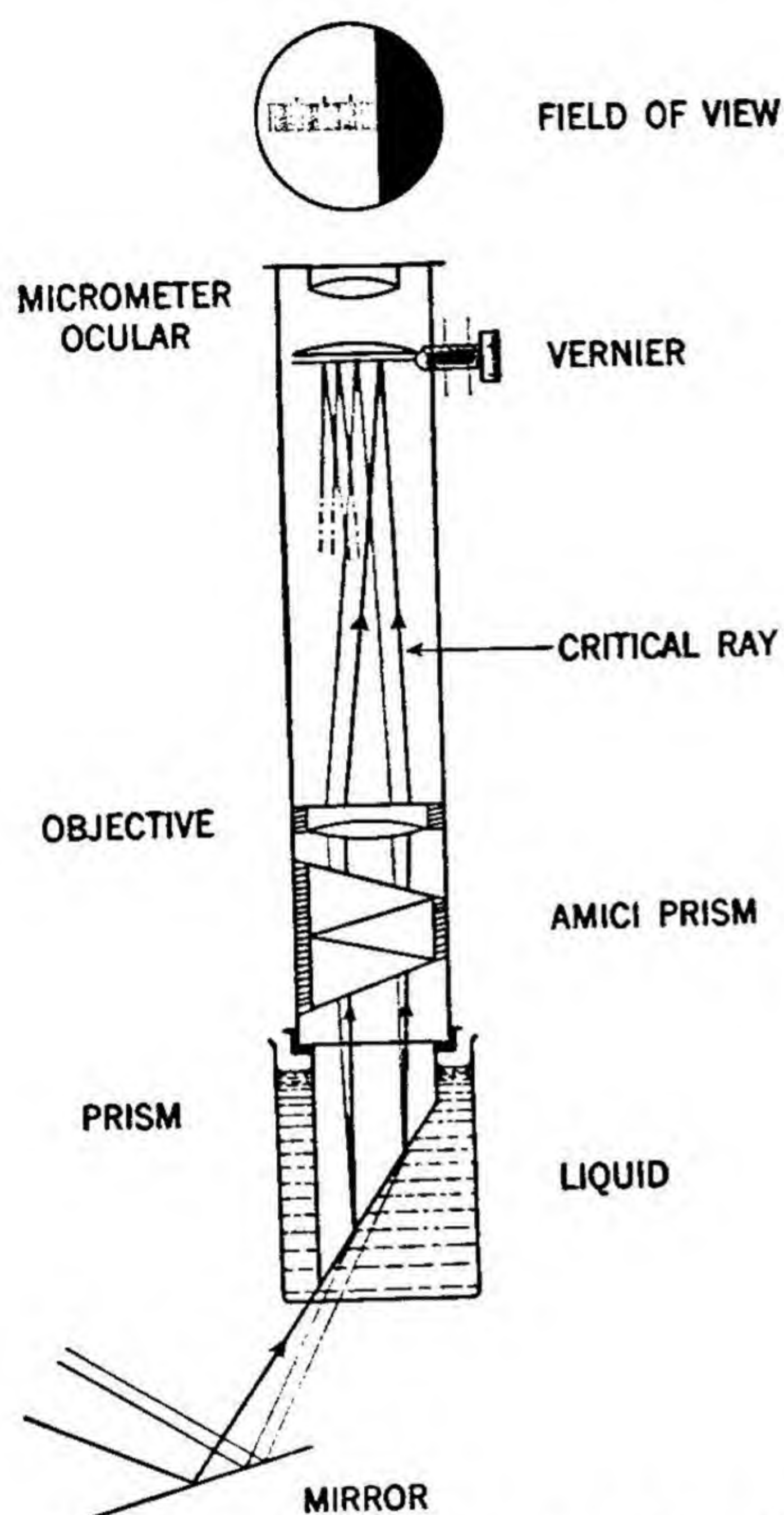


Fig. 265. Schematic diagram of the dipping refractometer.

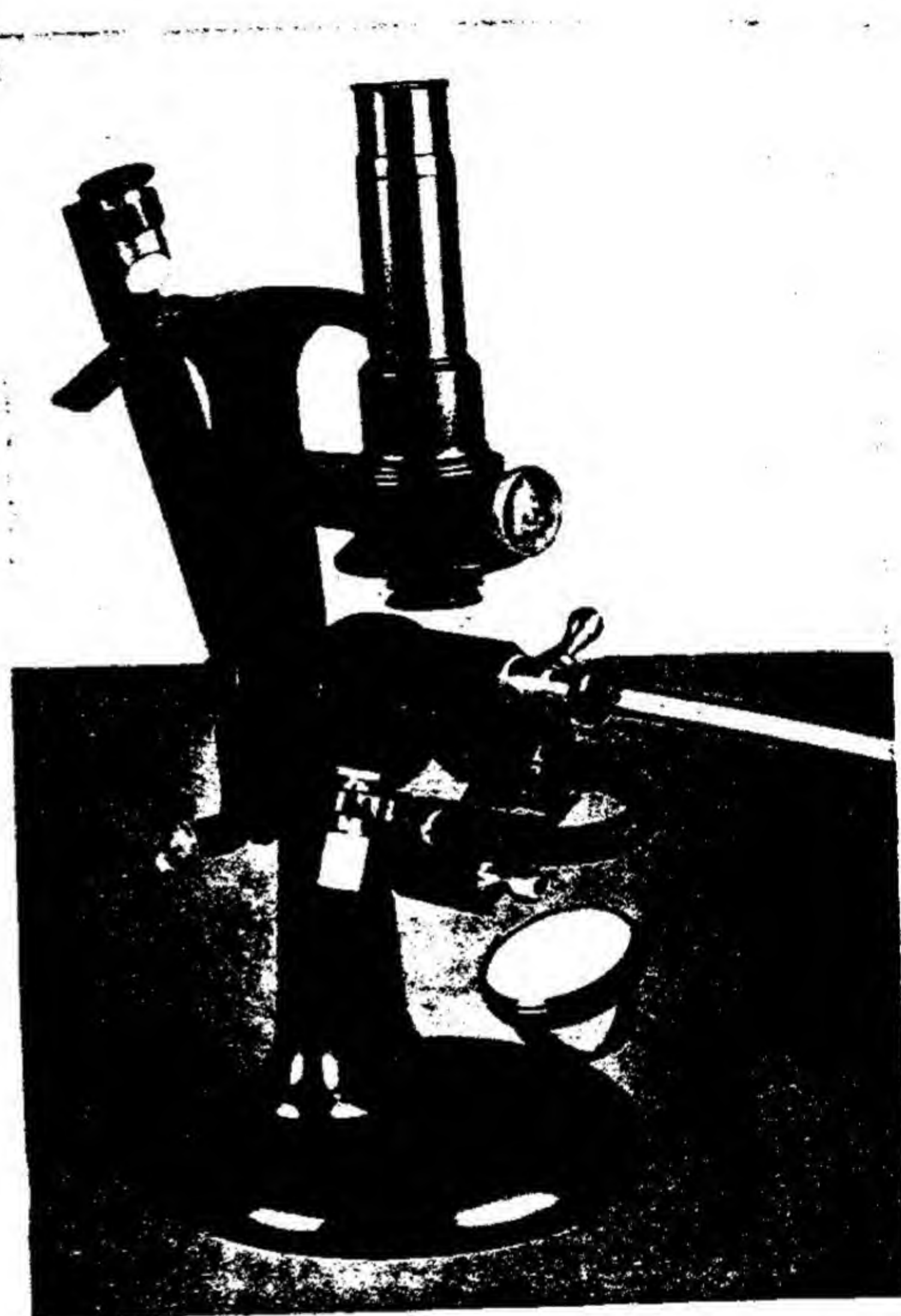


Fig. 266. The Abbe refractometer.

### The Abbé Refractometer<sup>7,8</sup>

This instrument (Fig. 266) has an optical system similar to that of the dipping refractometer. There are, however, two prisms (Fig. 267). The upper or refracting prism may be placed in a horizontal position and a drop of the liquid permitted to fall on its polished surface. It is then replaced in position and the two prisms are locked together. The lower prism has a rough-ground surface which diffuses the light and permits it to enter the liquid in all directions. A reflector directs light into the prism. The prisms are attached to a rotating arm which follows a curved scale giving direct readings of refractive index for  $D$  light. The prism arm is rotated until the dark border, as seen in the telescope, is set on the cross hairs.



Abbé refractometers have a range of 1.30 to 1.70 and 1.45 to 1.84 and an accuracy of  $\pm 0.0001$ . (The precision Abbé instrument is capable of an accuracy of  $\pm 0.00003$ .) Although less accurate than the dipping instrument, it has the

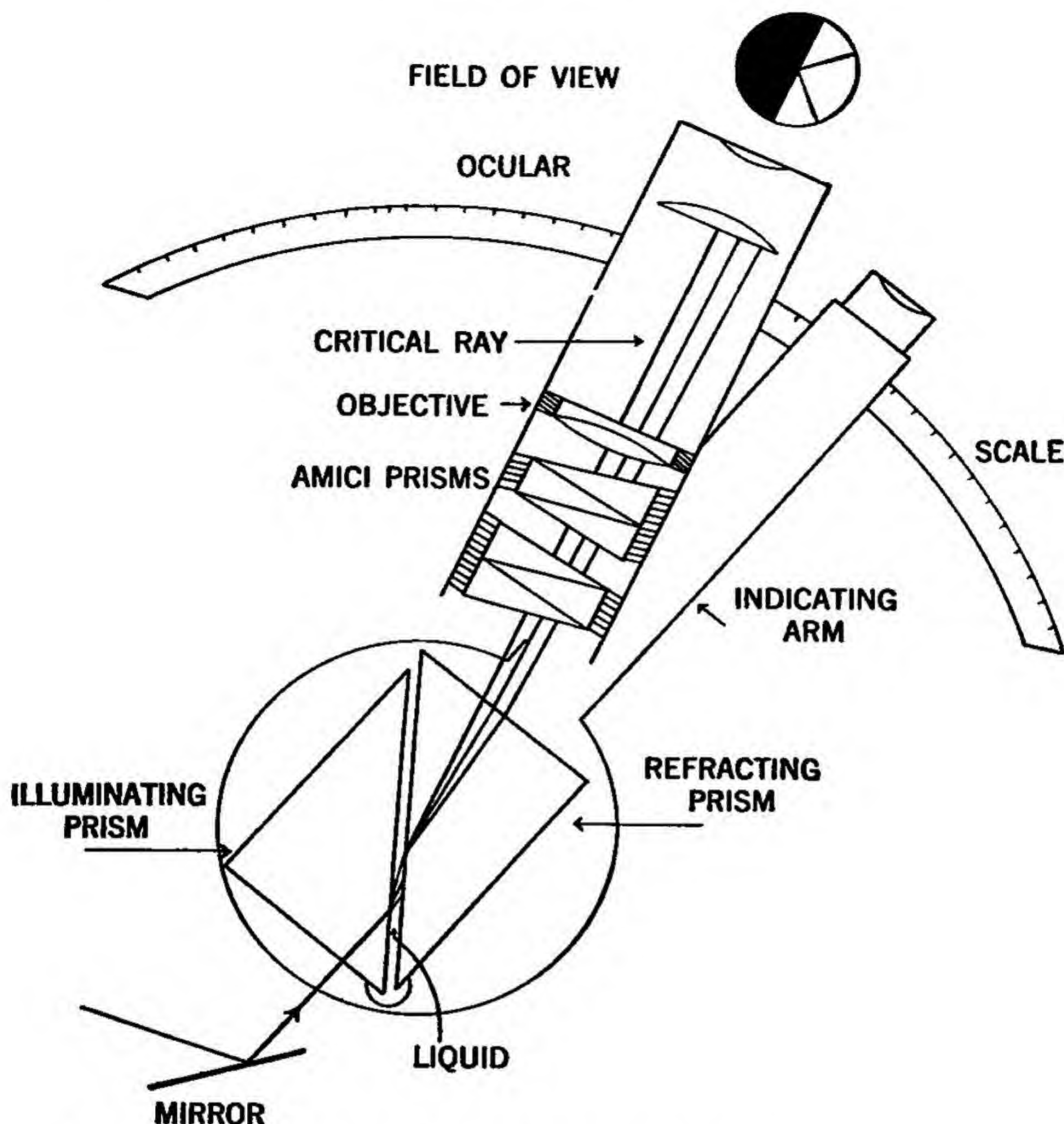


Fig. 267. Schematic diagram of the Abbé refractometer.

advantage of requiring only a drop of the liquid instead of a small beaker. In addition, the prisms are mounted in a jacket through which thermostated water can be circulated.

### Achromatization

It is preferable to use a monochromatic light source with refractometers, although they are designed so that white light may be used. Naturally, white light is dispersed by the sample. To neutralize this dispersion, Amici compensating prisms are used in both instruments. The compensating prism is designed to permit the passage of sodium *D* light undeviated. In the dipping refractometer one Amici prism is used. By rotating the prism the dispersion of light by the sample is neutralized. By means of a graduated collar the amount of partial dispersion can be estimated. This prism is located below the telescope objective.



In practice the collar is rotated until the dark border is sharp and the area free of color.

The Abbé instrument is equipped with two Amici prisms which can be rotated in opposite directions by moving a knob in one direction. Dispersion, without deviation, can be completely controlled. The instrument is adapted to the measurement of dispersion.

### 3. REFRACTIVE INDEX OF SOLIDS

Although the instruments described above are designed primarily for use with liquids, they can be used for transparent solids also, by adjusting the instru-

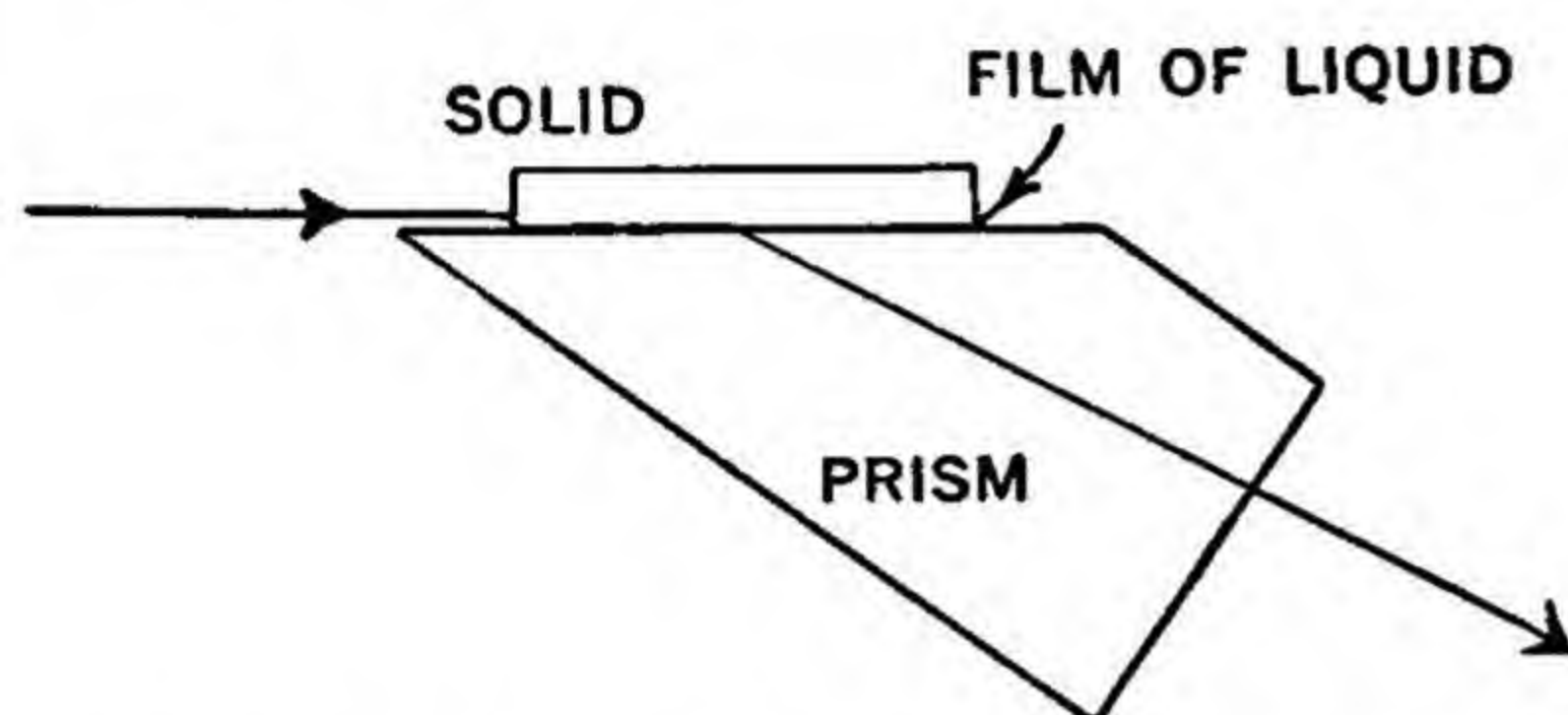


Fig. 268. Position of the prism in determining the refractive index of a solid.

ment so that the face of the refracting prism is uppermost (Fig. 268). The sample should be homogeneous and must possess two mutually perpendicular surfaces. It must be surfaced plane on one side by means of a felt polish. The necessity for this may be seen by considering the possibility of reflections from many directions when the

surface is rough. The plane surface is placed in contact with the face of the prism. To prevent internal reflections between the faces of the sample and the prism, good optical contact is obtained by applying to the prism surface a small drop of a liquid of higher index of refraction, such as alpha-bromonaphthalene ( $n_D = 1.66$ ). The sample is pressed carefully on the prism so that a bubble-free, even contact is obtained. The formation of a liquid wedge should be avoided, since this affects fourth decimal accuracy.

When the size of the sample is too small to permit polishing and shaping, the immersion method, which is described below, will be found more generally applicable. For powders the method of Le Blanc<sup>9</sup> is suitable.

#### Refractive Index by the Immersion Method<sup>10</sup>

Theoretically, if a transparent or translucent solid is immersed in a liquid of the same refractive index, it will be invisible because of the optical homogeneity of the system. This simple indication of refractive index is the basis of several fairly sensitive microscopic methods. Two cases must be distinguished: (1) isotropic substances, which have the same optical properties in all directions, and hence have only one index of refraction; (2) anisotropic substances, which may have different optical properties in different directions — for example, doubly refractive crystals which have two different indices of refraction.

#### Isotropic Solids

The laboratory will be most frequently concerned with the refractive index of glass particles which have been found as evidence in a burglary, assault, or a motor vehicle homicide; hence the following treatment will have particular



reference to glass samples. With fairly large samples the use of the microscope is not necessary in initial determinations. A simple procedure in approximating the refractive index of glass is to place the glass in a small beaker and add liquid of lower index than glass in sufficient quantity to cover the glass. Add to this, in small amounts, a liquid of a higher index of refraction. When the glass becomes invisible, remove a sample of the liquid and determine its index with a refractometer. Suitable liquids for this purpose are di-n-butyl carbonate ( $n_D^{20} = 1.411$ ), tri-n-butyl citrate ( $n_D^{20} = 1.455$ ), alpha-bromonaphthalene ( $n_D^{20} = 1.658$ ), and methylene iodide ( $n_D^{20} = 1.742$ ).

The general immersion method employs a series of liquids<sup>11, 12, 13</sup> of known index of refraction. The solid is immersed in several of these in turn until the visibility indicates the liquid of nearest index. This procedure may be followed instead of the one employing two liquids. Table 29 comprises an adequate series of liquids.

In place of a series of different liquids, two nonvolatile liquids can be combined in different proportions to give a series of liquids of different indices. The liquids mentioned above can be used or any other suitable combination. (See Exercise 2.)

Faick and Finn<sup>14</sup> have described a simple apparatus for measuring the refractive index of glass by the immersion method. The sample and immersion liquid are placed in a water-cooled tank. On one side of the tank a grid is placed and illuminated by sodium light. A telescope is focused on the grid from the opposite side of the tank. The index of the immersion liquid is varied until the grid image is seen without distortion. The accuracy of this method is about  $\pm 5 \times 10^{-4}$ .

An apparatus similar to the above in principle but more accurate and more elaborate has been described by Faick and Fonoroff.<sup>15</sup> A double diaphragm is employed to obtain oblique illumination. A monochromator is used to give a narrow band of light and also for the purpose of obtaining dispersion values. The system is excellent for rapid determination of refractive index for large samples of glass. The average error with this apparatus is  $\pm 2 \times 10^{-5}$ ; thus the accuracy approaches that of the refractometer.

### The Becke Line<sup>16</sup>

The image of a transparent object observed through the microscope is formed by refraction and reflection.<sup>17</sup> At the border line of the object a dark boundary line is observed because of this behavior of light. Many objects are surrounded by a narrow band of light when immersed in a liquid. This band is called the *Becke line*. When the object is immersed in a liquid of lesser refractive index and the objective is raised, the bright band moves toward the object; when the objective is lowered, the band moves away from the object. When the immersing medium is of a higher index, the observed motion of the Becke line is in the opposite direction. A rule may be formulated as follows: When the microscope is raised, the Becke line moves toward the substance of higher refractive index.



A simple explanation of this phenomenon may be given in the case of crystals, which are usually thicker in the middle than at the sides. In this shape the crystal behaves as a convex lens. When immersed in a medium of lower refractive index, the crystal will cause light to converge because of the shortened optical path at the sides of the crystal.

To observe the Becke line the condenser (low-power) should be lowered, the substage diaphragm stopped down, and an objective of low numerical aperture

TABLE 29\*

	$n_D^{20\text{C}}$
Methyl alcohol	1.3288
Water	1.3330
Acetone	1.3592
Ethyl acetate	1.3727
n-Hexane	1.3755
n-Heptane	1.3872
n-Butyl alcohol	1.3991
n-Butyl chloride	1.4022
1, 4-Dioxane	1.4223
Methyl cyclohexane	1.4235
Ethylene glycol	1.4318
Ethyl citrate	1.4434
Ethylene chloride	1.4453
Trimethylene chloride	1.4476
Cyclohexanone	1.4507
Cyclohexanol	1.4678
Diethanolamine	1.4782
Triethanolamine	1.4853
p-Cymene	1.4908
s-Tetrachloroethane	1.4943
Toluene	1.4957
Benzene	1.5017
Ethyl iodide	1.5138
Anisole	1.5178
Trimethylene bromide	1.5238
Chlorobenzene	1.5250
Methyl iodide	1.5310
Ethylene bromide	1.5383
o-Nitrotoluene	1.5466
Nitrobenzene	1.5526
Tri-o-cresyl phosphate	1.5582
Bromobenzene	1.5602
o-Toluidine	1.5725
Aniline	1.5864
Bromoform	1.5973
o-Iodotoluene	1.6095
Quinaldine	1.6120
Iodobenzene	1.6205
Quinoline	1.6272
s-Tetrabromoethane	1.6378
$\alpha$ -Bromonaphthalene	1.6585
Methylene iodide	1.74

\* Sold in 25-ml bottles by the Eastman Kodak Company.



(0.25 *N.A.*) is used, with a high-power ocular (10X to 20X). This procedure is followed in order that approximately parallel light may enter the object. The sample may be prepared by crushing in an agate mortar and placing on a slide with a cover glass. The immersing medium can be introduced by applying a drop on a glass rod to the slide near the cover glass. The liquid will then flow under the cover glass by capillary attraction.

### **Oblique Illumination<sup>18</sup>**

This is another immersion method in which unsymmetrical, oblique illumination is used with the microscope, either by swinging out the mirror or by displacing the condenser iris in its adjustable mount. On looking into the microscope the substance being tested will be shaded on one side. If the specimen is of higher index than the surrounding medium, it will appear shaded on the same side as the microscope field. If the index is lower than that of the medium, the shading will be on the side opposite to that of the field. When the medium and the substance have the same index, no shading is visible. Again, a series of immersion liquids is used and the test applied until a balance is reached. When white light is used a refinement of the method may be applied, if the index of the liquid is very close to that of the specimen, by observing the distribution of color about the crystal. When the bright side is blue and the dark side reddish-brown, the specimen and the liquid have the same index for yellow light. This is due to the fact that the liquid usually has greater dispersive power than the solid and has a higher index for blue than for red. In applying the oblique illumination test a low-power substage condenser should be used. The condenser is carefully focused. A low-power objective is employed. This method is not well suited to strongly birefringent crystals.

The quantity of liquids used in these procedures may be quite small — sufficient to fill the cavity on a microscope object glass. To measure the refractive index of the liquid special techniques can be used. Wright<sup>19</sup> describes the methods which have been devised for this purpose.

### **Anisotropic Solids**

These substances have more than one refractive index. It is necessary, then, to use a polarizing microscope and to apply the above methods for each of the two or three orientations of the crystal which gives a different index of refraction. The reader is referred to any standard text on crystallography or chemical microscopy for an adequate treatment of this subject.

## **4. REFRACTIVE INDEX OF LIQUIDS BY USE OF THE MICROSCOPE<sup>20</sup>**

If a refractometer is not available, the immersion methods described above can be used to determine the refractive index of a liquid by employing solids of known refractive index. Isotropic crystals should be used for convenience. Lists



of such crystals are available in handbooks. The method is not very accurate, however.

### EXERCISES

1. By means of a refractometer determine the index of refraction of a sample of whiskey. Determine from this the percentage of alcohol by volume. Compare this value with the proof printed on the bottle (which is not necessarily accurate). Place 25 ml of the whiskey in a distilling flask and collect the distillate at 80 C (see Chap. 27). Determine the volume of this ethyl alcohol and then add sufficient distilled water to make the volume exactly 25 ml. Determine the index of refraction of this mixture and compare the percentage alcohol with the other determinations. Calculate the percentage of alcohol by volume.

2. The following equation for the approximate refractive index of a mixture of two liquids is given:

$$n = \frac{n_1 V_1 + n_2 V_2}{V_1 + V_2}$$

where  $V_1$  and  $V_2$  are volumes of the liquids, and  $n_1$  and  $n_2$  are their respective indices. Using benzene and bromoform calculate the volume of bromoform which when mixed with 20 ml of benzene will yield a mixture of  $n = 1.600$ . Compare the theoretical value with that determined by means of the refractometer.

3. Collect four samples of glass from different sources. Determine the refractive index of each using both the Becke line and oblique illumination methods.

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# CHAPTER 41

## SPECTROCHEMICAL ANALYSIS

Up to this point little consideration has been given to the limitations frequently imposed upon the analyst in the police laboratory owing to the amount of sample that is obtainable as evidence. For the most part, the various procedures described so far have assumed the samples to be adequate in quantity. In many cases, however, the circumstances are such that the evidence is quite meager as to the amount available for analysis. A few specks of mud, a metal fragment, a few chips of paint, a smear of rouge or lipstick, are some of the clue materials commonly presented to the laboratory for analysis. Ordinary chemical methods are inadequate in these cases and other means must then be used.

In the field of chemistry the spectrograph makes it possible not only to simplify greatly the problem of determining the elements present in an unknown substance, but to cope, also, with the task of analyzing quantities of matter which are so minute as to be beyond the range of microchemistry. It is precisely this ability to examine minute traces which makes the spectrograph so valuable to the forensic analyst. His two major problems are solved: (a) the analysis of evidentiary traces which are too small in quantity to be analyzed by the conventional chemical methods; (b) the characterization of a substance by means of its inevitable impurities, thus permitting him, say in a comparison of known and unknown samples, to establish with great certainty the common (or dissimilar) origin of two specimens.

Despite the complexity of the problems which the spectrograph can solve, it is inherently a simple instrument both in its mechanism and operation. Essentially it is an optical apparatus which produces images of a narrow slit of light. In its simplest form a substance is burned in front of this slit. It is found that each element in the form of a luminous gas emits light waves which are characteristic of that particular element. Just as a given tuning fork or piano string can send out only definite, predictable frequencies, so the element is restricted to giving forth light of certain wave lengths and frequencies. The characteristic light entering the spectroscope through the slit is broken up by a prism into its many component colors (which correspond to frequencies). The emergent light is focused for the eye by a telescope. The resulting view is a strip of light lines of different colors (Fig. 269). These lines are the images of the slit. If a photographic



Na



Li



K



Ca



Sr



Ba



Fig. 269. Spectrum chart. (By permission from *Inorganic Chemistry*, by H copyrighted 1912 by McGraw-Hill Book Company, Inc.)







plate is substituted for the eye, the negative will show a series of black lines of varying intensity.

If a substance composed of many elements is burned, it is found that the presence of each element can be detected in the spectrum. Thus the constituent elements of the substance can be unfailingly determined. It is for this reason that a spectrum has been called the "fingerprint of a substance" (see Fig. 269). A flake of paint on the end of a jimmy, metal filings on a hacksaw blade, abrasive material in a crankcase, plaster or dirt on a shoe, a fragment of glass, and the many other clue materials with which the police scientist deals can often be unmistakably "fingerprinted" in this manner. Additional examples of the use of the spectrograph in criminalistics are described by Hoover,<sup>1</sup> Newman,<sup>2</sup> Walker,<sup>3</sup> Rankin,<sup>4</sup> Gerlach,<sup>5</sup> and Sannié.<sup>6</sup>

When a suspect is apprehended then, a spectrographic examination of the clue materials discovered in his possession and similar materials obtained from the scene can contribute greatly to the solution of a crime. Thus spectroscopy, by extending the field of chemical analysis from macro- to semimicro-quantities, is an invaluable aid to criminal investigators, since the clue materials connected with a crime are most often available only in limited amounts. Through the use of this powerful tool small traces, which might otherwise be useless, are converted into damaging, objective evidence which cannot be gainsaid easily.

## 1. THE THEORY OF EMISSION SPECTRA

In order to understand the basis of spectrochemical analysis, a knowledge of modern concepts of the origin of various types of spectra (and spectral lines) is required.

All spectra may be divided into two types: emission spectra, which arise from an excited source of energy; and absorption spectra, which have their origin in the absorption of energy by the substance in question.

Emission spectra may be classified further according to their origin, e.g., incandescent solids, excited molecules, and excited atoms (or ions). The continuous spectra and band spectra, respectively, of the first two sources will be neglected in this chapter and only emission spectra of excited atoms (or ions), which are characterized by sharply defined lines and which are of greatest use in analytical work, will be considered (Fig. 270).

While a rigorous treatment of spectral theory requires an extended mathematical treatment, it is, nevertheless, possible to present a very simplified version of modern atomic structure (if not taken too literally) which will suffice to explain the origin of the spectra with which the criminalistician is mainly concerned.

Matter is believed to be built up by combinations of over **Fig. 270.**  
spectrogi



ninety-two basic substances, which are referred to as elements. Modern physicists have found that there are more fundamental building blocks of matter than the atoms of the elements. The atoms of the various elements differ in the combinations and spatial arrangements of the ultimate particles of atoms — electrons which carry a negative electrical charge, protons which are positively charged, and neutrons which carry no charge. Neutrons and protons are of equal mass and are about 2000 times heavier than electrons.

For a clearer concept of the atom, a rough analogy may be drawn between the sun, together with the planets which revolve around it, and the nucleus of the atom with the planetary electrons which revolve around it. The nucleus always contains a positive charge which is just balanced by the collective negative charge of all the planetary electrons, so that the atom as a whole is uncharged. Atoms of the various elements differ from each other by the number of planetary electrons which they contain.

There is a "normal" state for an atom in which certain "ground" conditions obtain, but when energy is imparted to the atom these conditions are disturbed. For example, if a substance is heated in a Bunsen flame, the energy which is absorbed causes some of the planetary electrons of the atoms to "jump" to orbits which are farther from the nucleus. The orbits which the planetary electrons may occupy are restricted.

A definite relationship exists between the energy which an atom absorbs and the energy it radiates when it returns to a less excited state or to the "normal" state. From modern theory of the atom it is known that the relation between two energy states can be expressed by  $E_a - E_b = h\nu$ .  $E_a$  and  $E_b$  represent the energy values of state  $a$  and state  $b$  respectively;  $h$  is a constant, known as *Planck's constant*; and  $\nu$  is the frequency of electromagnetic energy absorbed or radiated. This frequency  $\nu$  is related to the wave length of the absorbed or emitted light energy in such a way that the product of the two is always a constant  $c$ , which is the velocity of light.

Since the number and spatial arrangement of the planetary electrons of atoms vary from element to element, each element absorbs and emits energy in accordance with its unique electron pattern. Therefore, the spectrum, which is simply the ordered arrangement of emission effects according to the frequencies of light energy radiated by an atom returning from an "excited" to a less "excited" or to its "normal" state, should be characteristic for each element. It is upon this concept that spectrochemical analysis is based. The emission spectra of practically all the elements are well known. In practice, however, the emission spectra of about 70 elements only may be obtained using standard arc and spark sources. The emission spectra of these elements have been the subject of intensive studies by many investigators and may be employed as a means of identification in a qualitative analysis.

## 2. THERMAL AND DISCHARGE-TUBE METHODS OF EXCITATION

The source of light which is analyzed in the spectrograph consists of atoms of which the planetary electrons are falling back from higher, excited energy



levels to lower energy levels. The method used to impart the necessary energy may vary from a mere flame source to more vigorous excitation methods which employ electricity in the form of a discharge tube, arc, or spark.

### **Thermal Methods**

This method consists of heating the substance in the flame of a Bunsen, acetylene, or other type burner. As only relatively low temperatures are obtainable by this means, it is considered to be a mild method of excitation and is used mainly in analysis of alkali and alkaline earth metals. The detection of sodium and its differentiation from potassium by cobalt-blue glass is a simple and well-known example of this type of spectral analysis.

For serious work by this method the vaporizing technique of Lundegårdh,<sup>7</sup> by which it is possible to detect some thirty-two elements, should be used. An article by Cholak and Hubbard will also be found helpful.<sup>8</sup> The forensic worker, however, is seldom if ever concerned with thermal techniques.

### **Discharge Tubes**

Discharge tubes may be used for the analysis of gases, particularly the rare gases. The method of excitation consists of impressing a high potential across electrodes in a closed tube containing, at reduced pressure, the gas to be studied.<sup>9</sup> Under these conditions an electric spark jumps across the electrodes and the energy of the discharge is absorbed by some of the atoms of the gas. These excited atoms radiate energy upon returning to their "normal" state. Discharge spark spectra are highly characteristic and may be used to identify gases. They are of little moment, however, in forensic work.

## **3. THE DIRECT-CURRENT ARC**

The direct-current arc is probably the most widely used and generally applicable method of excitation for nonroutine work in qualitative analysis.<sup>10</sup> It is considered to be the most satisfactory because it requires little equipment, is simple to operate, and can be conveniently used for metals, alloys, solutions, and nonconducting solids, i.e., for almost any sample, permitting the entire sample to be completely consumed. The arc produces spectra of many lines being, therefore, a highly sensitive method of excitation. The advantage of the arc over the spark method (v.i.) is in its high sensitivity. Arc spectra are more representative of the sample; whereas spark spectra, owing to the selectivity of the spark discharge, are not as typical.

An arc is formed by bringing two charged electrodes together, then separating them slightly. When the electrodes touch, they complete an electrical circuit, resistance is offered, heat is generated, the substance being examined is volatilized, and energy is absorbed, later to be emitted as characteristic radiations which are analyzed by the spectrograph.

Carbon or graphite electrodes are generally used in the form of rods. Graphite is usually chosen as the electrode material because it may be obtained in



relatively pure form and may be readily formed to the desired shape. Its simple spectrum offers no interference in the regions in which the analyst is generally interested (except for cyanogen bands); it is a good conductor, has a high heat of sublimation, and does not form an oxide crust. Very high grade graphite, designated as *special spectrographic graphite*, should be used in forensic spectroscopy where trace elements are of the greatest importance. Excellent directions<sup>11</sup> are available for those interested in purifying commercial graphite rods.

Two electrode sizes are generally used, 4.8 mm (0.19 in.) for solid samples, and 6.3 mm (0.25 in.) for solutions. The upper graphite electrode, which is usually the cathode, is shaped to a point, and the lower electrode, usually the anode, is drilled out to form a cup or well from 5 mm to 12 mm deep.<sup>12</sup> The cup is made deeper when volatile constituents, such as mercury, are anticipated.

The substance (5–20 mg of solid or 0.05–0.20 ml of solution) which is to be analyzed is placed in the cup of the lower electrode. The arc is struck by drawing a graphite rod across the two electrodes which are moved to within 1–2 mm of each other for this purpose. The electrodes are then separated by approximately  $\frac{1}{2}$  to 1 cm and the central portion of the arc, which is free from the continuous spectrum of the incandescent electrodes is used to illuminate the slit of the spectrograph. In order to do this, the electrode holders usually are readily adjustable so that the arc may be aligned horizontally and vertically. If the arc wanders, these adjustments are of great value in keeping the light source focused on the slit.

The usual potentials range from 110 to 250 volts; 4 to 15 amperes of direct current are used. The ordinary procedure is to begin with a low current and, as the volatile constituents pass off, the current is increased. Complete, uniform, and continuous vaporization of the sample is required for a reliable analysis. Higher potentials have a tendency to steady the arc and prevent its wandering. This tendency to flicker and wander is the most serious disadvantage of the method, but techniques such as rotating the lower electrode and using high potentials help to minimize this difficulty.

#### 4. METHODS FOR INCREASING SENSITIVITY OF THE ARC

##### Cathode Layer Method<sup>13</sup>

It has been found that the region nearest the cathode possesses a greater concentration of ions which have received more energy than average for the rest of the arc, and hence may be used whenever high sensitivity is required. In the *cathode layer* or "Glimmschicht" method, which is a modification of the usual arcing method, the lower electrode (which is generally the anode) is made the cathode or negative pole. The region 1 to 2 mm above this pole is focused on the slit, care being taken to avoid having the incandescent pole illuminate the slit also.

The arcing is usually done at a difference of potential of 220 volts (d-c); a starting current of 3 to 4 amperes, which is slowly raised to 8 or 10 amperes, is used. Electrodes of 3 mm diameter are employed in this method, to reduce arc



wandering. An important consideration which is suited to the needs of the forensic spectroscopist is that quite a small sample, 2 to 3 mg, is sufficient for analysis by this method. A disadvantage, however, arises from the necessity and difficulty of focusing a small portion of the arc on the slit.

### **Moving Plate Method**<sup>14, 15</sup>

Another modification of the direct current arc that must be mentioned, because it offers a means of increasing the sensitivity of detection of trace elements, is the *moving plate method*. As the name implies, this modification consists of moving the photographic plate vertically to a new position while the arc is in operation. This movement may be done at definite intervals, i.e., every 20 seconds, moving the plate 1 to 2 mm each time, or in a slow, continuous manner during the entire arcing period. Very great sensitivity is claimed for the method; the successively exposed areas record the elements fractionating at that time during the arcing. Trace elements, which might otherwise be lost because of background, are found in samples by this modified technique when the usual arcing method fails to disclose their presence. In routine industrial spectrographic work this method is not generally employed because it is time-consuming, and the conventional arc method is usually satisfactory. However, in criminalistics, where maximum conditions of sensitivity are required for the detection of all the trace elements possible, this modification may be found useful.

### **The High-Voltage Alternating-Current Arc**<sup>16</sup>

This is a modified arc method which enables the analyst to obtain more reproducible results because of its steadiness. In addition, this method has many of the characteristics and advantages of the low-voltage direct-current arc as well as certain advantages of its own, such as smaller sample requirements, reduction in background, and low heating effect on the electrodes. Some workers<sup>17</sup> claim that in certain cases this method is superior in sensitivity and precision to the direct-current arc. The distance of separation (0.5 to 1.50 mm) of the two electrodes, the potential (2200 volts) and amperage (2 to 8 amperes) must be carefully controlled for satisfactory results. Ruehle and Jaycox<sup>18</sup> have designed a high-voltage a-c arc circuit which may be tied in with an ordinary direct-current arc and condensed spark circuits. In general, its precision, sensitivity, and fields of application are intermediate between those of the direct-current arc and the condensed spark (v.i.).

## **5. SPARK DISCHARGE METHODS**

An electric spark operated from a secondary transformer giving from 10,000 to 50,000 volts provides a source of high excitation, which is readily controlled. Ordinarily a condenser is connected in parallel with the discharge circuit in order to increase the current.

Thus, there are two types of electric spark discharges — condensed and uncondensed — which may be used to excite substances for spectral analysis.



The lines of spark spectra are thought to arise mainly from excited ions. The spark method is less sensitive than the arc method, but certain nonmetals such as boron, carbon, phosphorus, silicon, and tellurium may be excited by the spark and emit characteristic lines because of the greater energy imparted by the exciting source.

Although more energy is imparted to the atoms than by arc methods, i.e., the effective temperature of the source is higher than in the arc, the electrode temperatures are not as great. Thus, easily volatilized substances such as solutions and low melting point alloys are better analyzed by this means.

When the examination is to be confined to a small region of a metallic specimen (such as in the analysis of paint specks on a jimmy), or if the specimen is to be analyzed with a minimum of damage, spark techniques are more suitable than arc methods. On metallic specimens, various layers of thin coatings or platings are best identified by low-power spark discharges. These factors together with the small quantity of sample which it is possible to analyze by the spark technique, constitute the principal advantages over the arc method of excitation. The stability and reproducibility of spark methods are also of great importance, particularly in quantitative work.

Alternating current with the potential varying from 10,000 to 50,000 volts is used, so that precautions must be taken to have good insulation and protection of the electrodes for the safety of the operator.

Nonmetallic samples (such as a rock that is to be analyzed quantitatively) are usually reduced to powder form and mixed with deashed natural graphite (1 part specimen, 2 parts graphite). This may be pressed into a pellet by means of a briquetting press, or merely packed into the hollow of a carbon or aluminum electrode; a graphite rod is used as the counter-electrode. The spark gap usually is from 3 to 6 mm in length.

### Condensed Spark<sup>19</sup>

This is probably the most widely used spark method. The effect of the condenser is to increase greatly the current discharged across the spark gap. Hence, more parasitic lines owing to oxygen and nitrogen are found in these spectrograms. It is possible to examine both solids and solutions by this method.

While formerly it was conventional to use an uncontrolled or free-running spark, it has become increasingly popular, particularly for routine quantitative work, to use a more refined excitation unit in which the spark is controlled. Figure 271 is a typical circuit of a controlled spark unit. The inductance,  $L$ , represses the objectionable background spectra of the air mentioned above; the rotating synchronous auxiliary spark gap,  $A$ , steadies and stabilizes the spark so that uniform, reproducible lines are obtained for quantitative analysis. This auxiliary gap also serves as a timing switch; the sample to be analyzed is placed at  $G$ , the spark gap; a capacitance,  $C$ , a resistance,  $R$ , and a high-voltage transformer,  $T$ , complete the secondary circuit.

A low-powered spark discharge of this type is very useful in making localized



tests such as are necessary in the case of small specks of paint on a jimmy, or other burglar's tool. This method is particularly useful in the analysis of thin coatings that have been plated successively on to the surface of a piece of metal. In this case a technique similar to the moving plate method is employed. The

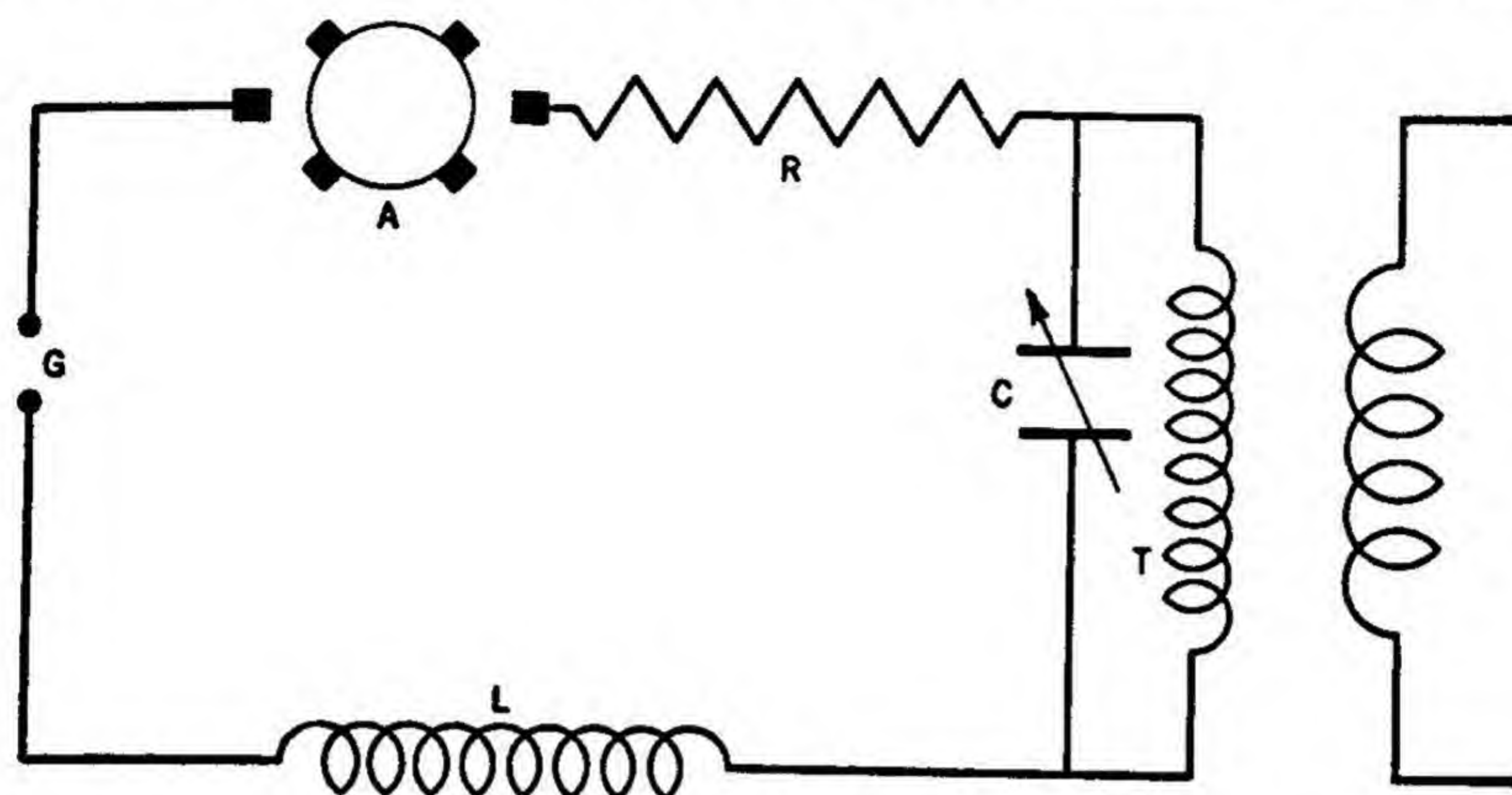


Fig. 271. Circuit of a condensed spark.

spark is allowed to impinge on a selected spot until it has penetrated all of the plating. During the discharge of the spark the photographic plate is moved at regular intervals, giving as a result, a series of spectrograms representing the composition at different depths of penetration of the plating.<sup>20</sup>

### Uncondensed Spark

This method of producing a spark results in spectral lines that are less intense than those obtained with a condensed spark. On the other hand, it has been claimed that greater sensitivity in the analysis of solutions is possible by this means.<sup>21</sup> If large amounts of organic material are present in the solution, e.g., as in exudates, strong objectionable background spectra result. Solids such as teeth, bones, and gallstones may be analyzed in this light source. The uncondensed spark is seldom used by spectrographers at present.

### High-Frequency Spark<sup>22</sup>

The spectra which result from this method of excitation resemble more closely arc spectra than they do spark spectra. Because of the high frequency, even nonconducting substances are penetrated, the current being carried through to the metal plate or electrode which is placed underneath. This method is fairly sensitive and is suitable for analysis of deposits on moist filter paper. It is also applicable to analyzing untreated biological tissues. Of particular interest is the use of the high-frequency spark in analysis of tissue that has sustained a gunshot wound.

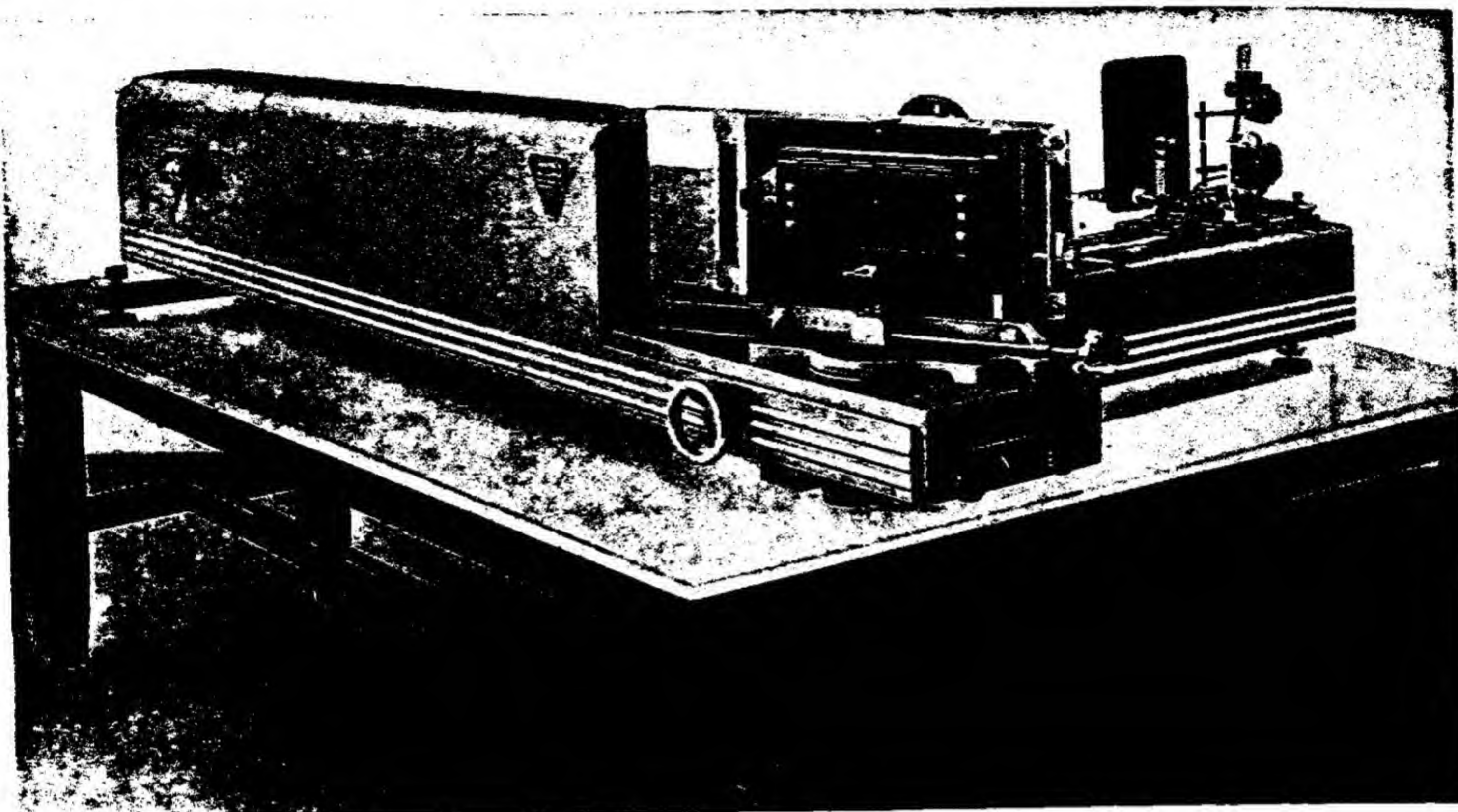
## 6. CHOICE OF INSTRUMENT AND OTHER EQUIPMENT

Spectrographic instruments may be classified according to the means used to obtain dispersion of the light rays. Accordingly, we have the prismatic spec-

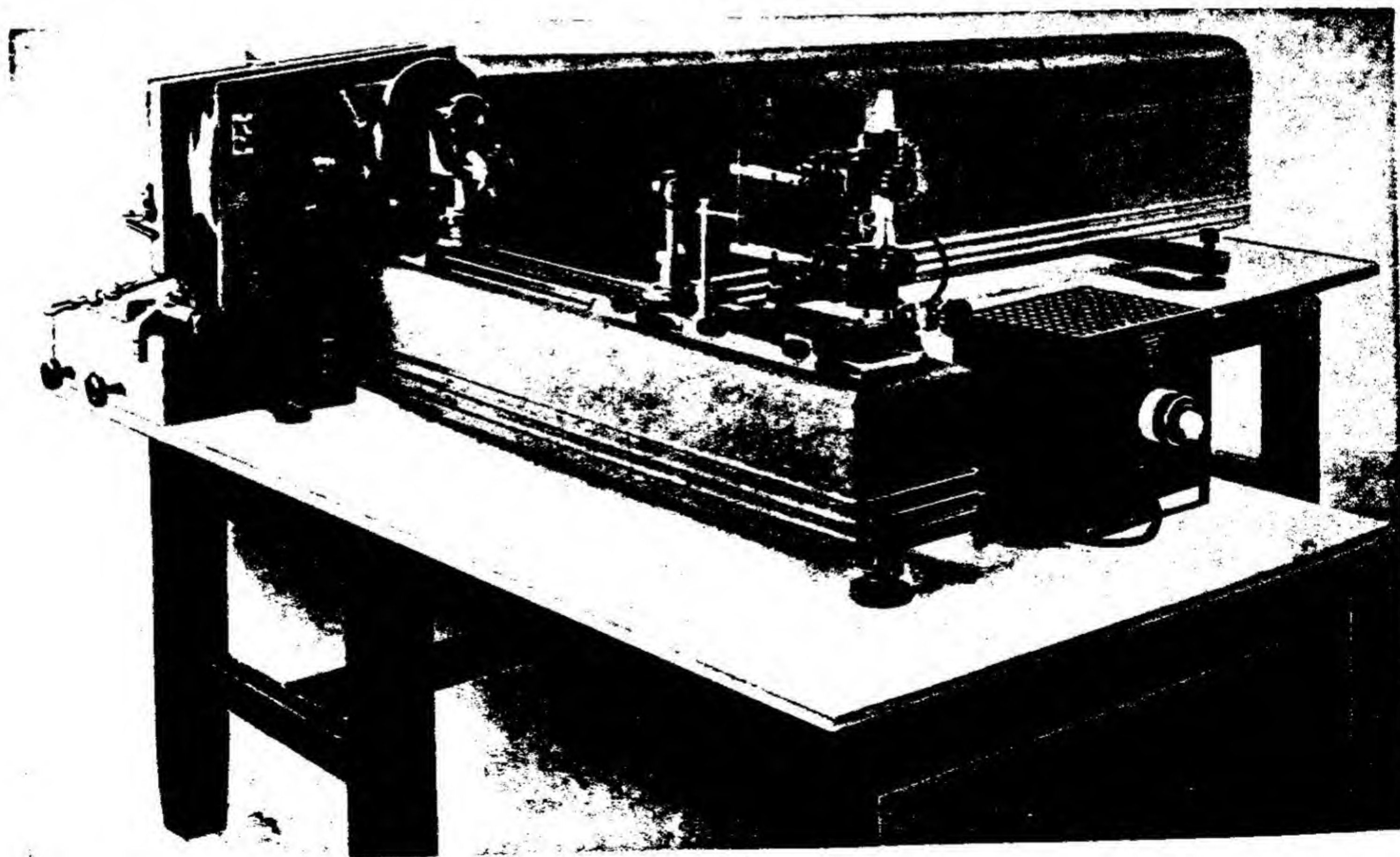


trograph, in which the rays are refracted, and the grating type, in which dispersion is achieved by diffraction.

The long focal length (180 cm) quartz prism (Littrow type) spectrograph (Fig. 272) has been chosen to provide examples of the applications of spectro-



(a)



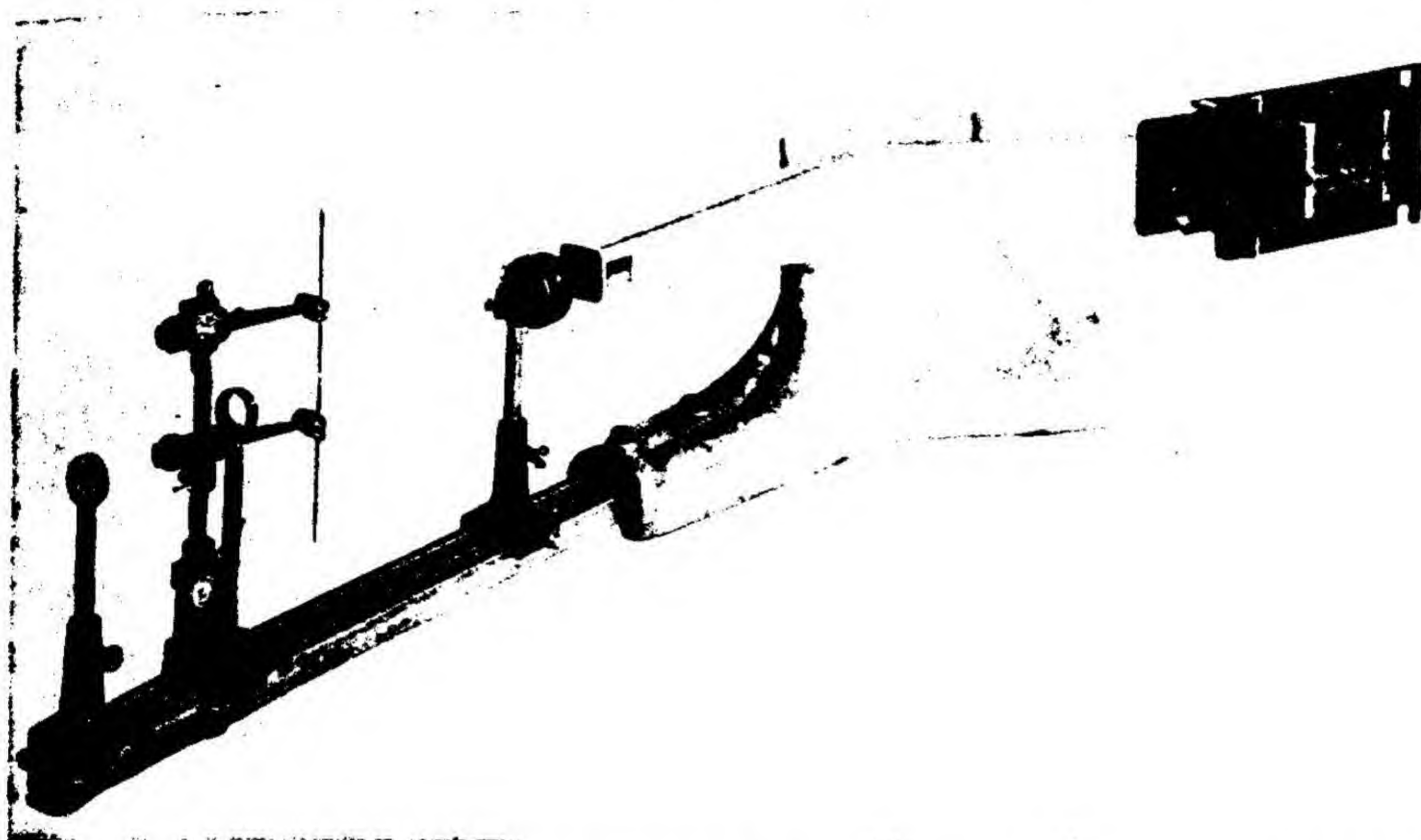
(b)

Fig. 272. Bausch and Lomb large Littrow spectrograph (180 cm), (a) the plate holder is visible; (b) the illuminating unit is visible. (Courtesy, Bausch and Lomb Optical Co.)



raphy partly because of the wide range of its uses in the field of forensic spectrochemical analysis, and partly because of the authors' familiarity with the instrument. A quartz prism is required because it permits transmission of energy in the ultraviolet, thus making possible analyses in that region where the most sensitive lines of the majority of elements appear. Some spectrographs of this type are arranged so as to permit a prism or diffraction grating to be used interchangeably, depending upon the nature of the material being analyzed and the preference of the spectrographer.

The less expensive, 60 cm focal length, medium-sized spectrograph (Fig. 273) is also satisfactory. When only a minute quantity of evidence is available



**Fig. 273. Hilger medium-size spectrograph (60 cm).** (Courtesy, Jarrell-Ash Co.)

it may possess certain advantages because of its superior light-gathering power. The greater range of wave length covered in a single spectrogram may also be advantageous in certain cases. Analysis of soil materials for the rare earths and of metals for nickel, chromium, and other elements of complex spectra, however, requires that an instrument of high dispersion and resolution such as the 180 cm Littrow type be available. Ideally, the completely equipped forensic spectrographic laboratory should possess both types. The initial cost of either or both instruments is almost negligible, if we consider the number of useful years of service without additional cost for repairs or replacement, not to mention the number of man-hours saved by the frequently conclusive results achieved when samples of evidence have been examined with either of these instruments.

In addition to at least one of the instruments above, the following equipment represents the minimum required in a forensic spectrographic laboratory:<sup>23</sup>

Excitation sources, including a direct-current arc and a conventional spark source.



A comparator or projector for visual examination of spectrograms.

Mechanical and chemical facilities for the preparation of the samples.

Wave length tables and charts, as well as other reference books (see sec. 17 below).

Photographic facilities.

## THE PRINCIPAL PARTS OF THE SPECTROGRAPH

The diaphragm, slit, dispersion element, the collimating lens, camera lens, and the photographic plateholder, constitute the principal parts of a spectrograph.

### 7. LENSES

The first lens ( $L_1$  in Fig. 274) encountered by the light rays from the source is not, strictly speaking, a part of the spectrograph. Its function is to illuminate

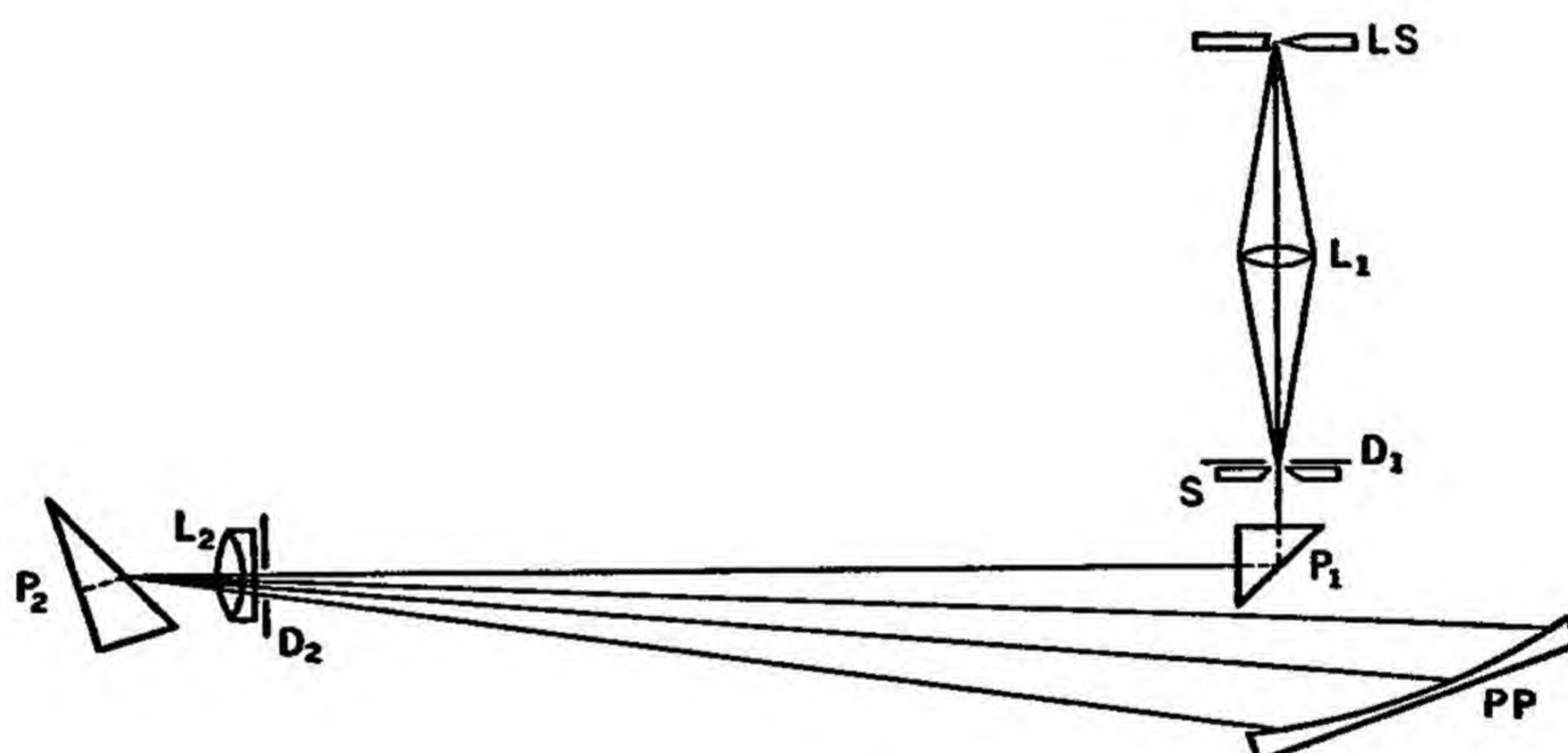


Fig. 274. Schematic diagram of the Littrow-type spectrograph.

the slit so that the collimating lens ( $L_2$  in Fig. 274) of the spectrograph is filled by a cone of light. This latter lens serves to render parallel the light rays which emerge from the slit with the result that only parallel light enters the prism. The collimating lens should fill the prism with light in order to have more energy fall on the plate; it is also a condition required for obtaining the optimum resolving power of the instrument (sec. 9). In the Littrow-type spectrograph the long focal length collimating lens is also used to focus the rays from the prism on the photographic plate ( $PP$  in Fig. 274). By tilting the photographic plate, the difficulties caused by chromatic aberration are eliminated. An attempt is also made to design the collimating lens so that the photographic plate will not have to be bent too greatly. Spherical aberration and coma are corrected for in this lens. A diaphragm ( $D_2$  in Fig. 274) may be used to reduce coma by elimination of the most oblique rays striking the lens.



## 8. SLIT AND DIAPHRAGM

The slit ( $S$  in Fig. 274) serves as the entrance to the spectrograph for the light from the source. The lines recorded on the photographic plate are reproductions of the slit (at the various wave lengths after the light has passed through the prism) so that any imperfections or defects are mirrored in the lines of the spectrogram. The jaws of the slit therefore must be mechanically perfect and the edges must be sharp, straight, and parallel, bearing no nicks, and must be free of dust particles. The width of the slit should also be adjustable, for in critical work where maximum resolution is required, the slit width which should be used is about equal to  $4f\lambda/D$  where  $f$  is the focal length,  $D$  is the effective diameter of the collimating lens, and  $\lambda$  is the wave length of light under examination. For example, the slit width which is most suitable for resolving the iron triplet at 3100Å (assuming a large 180-cm Littrow, with a lens diameter of about 10 cm) is

$$\frac{4f\lambda}{D} = \frac{4 \times 180 \times 3100}{10} = 2232 \times 10^2 \text{Å} = 0.022 \text{ mm}$$

A suitable slit, then, requires careful design and high-caliber workmanship since the quality of the spectral lines and, to some extent, the performance of the spectrograph, are related to the characteristics of the slit.

A diaphragm ( $D_1$  in Fig. 274) is usually placed in front of the slit to regulate the slit length and hence the image height. This diaphragm, which is generally shaped like a wedge or fishtail, enables the operator to vary the slit height from zero to maximum height, which is the length of the slit itself. Another diaphragm arrangement in which a series of openings is placed in echelon formation was devised by Hartmann. With the Hartmann arrangement it is possible to make a series of spectrograms on the same plate merely by moving the diaphragm and without moving the photographic plate; any lateral shift of the plate (such as might happen while adjusting it for a new exposure) is eliminated by using this diaphragm.

## 9. DISPERSION ELEMENTS

### Prisms<sup>24</sup>

The various parts of the spectrograph studied so far serve to present the light to be analyzed in a fashion suitable for its utilization by the prism ( $P_2$  in Fig. 274). On entering the prism the light is refracted by the quartz or glass medium. The degree of refraction is a function of the wave length of the light, so that the emergent beam is composed of many light rays which have been deviated by amounts differing from their original common direction according to their respective wave lengths. This phenomenon is called *dispersion* and is expressed mathematically as  $d\theta/d\lambda$ , or the ratio of the angular change or deviation ( $d\theta$ ) of the incident light ray per unit change in wave length ( $d\lambda$ ). Two of the factors which affect the dispersive power of the prism are the angle of the apex and the composition of the medium (i.e., glass, quartz, rock salt, etc.), since the deviation



or angular change of the beam varies with the index of refraction of the medium  $d\theta/dn$ . Another factor is the change of index of refraction with wave length  $dn/d\lambda$ . The relation between these factors and dispersion is simply:  $d\theta/d\lambda = d\theta/dn \cdot dn/d\lambda$ .

The parallel light rays entering the prism in Fig. 275 are from the collimating lens and they are assumed for the purpose of the illustration to consist only of

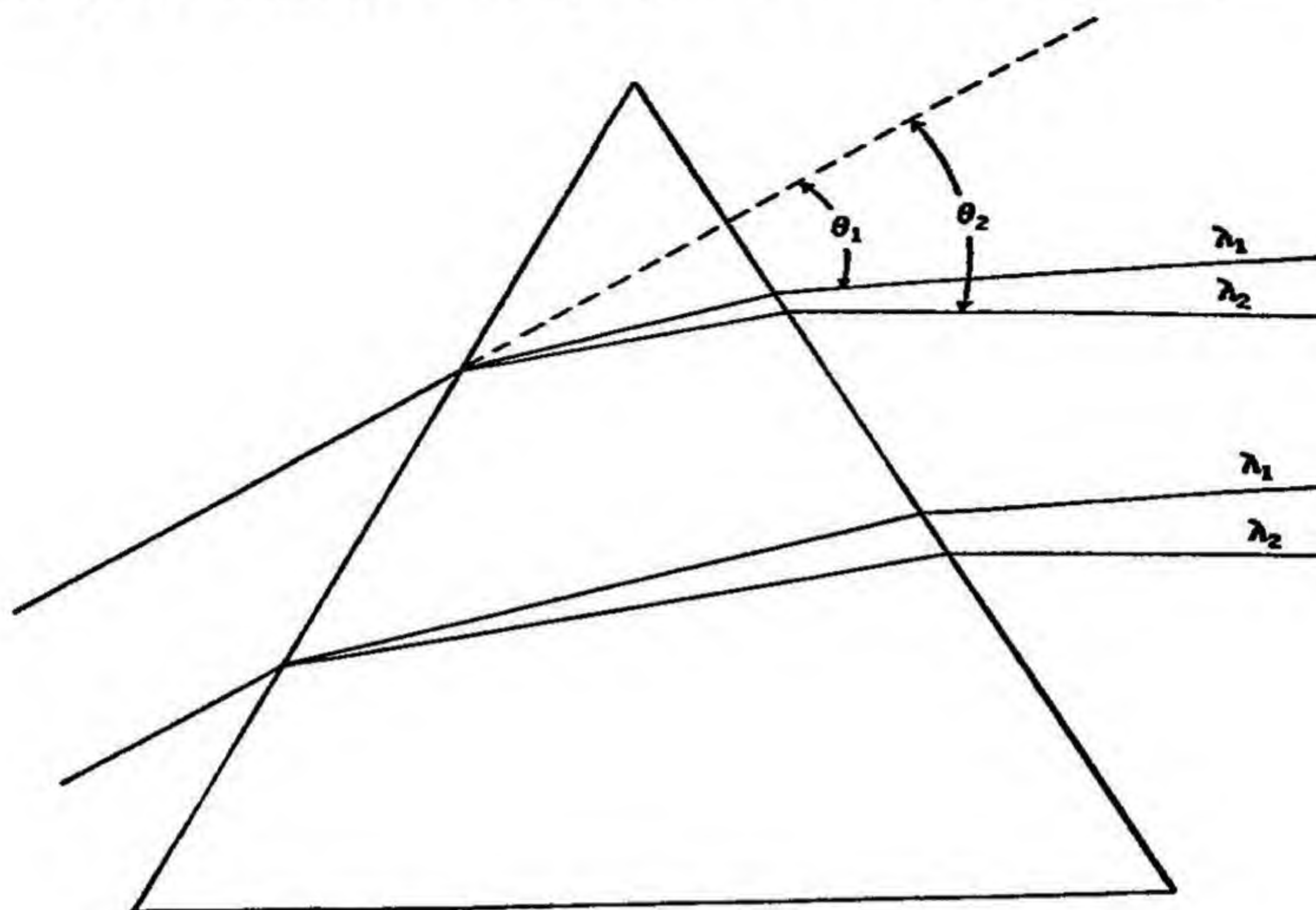


Fig. 275. Dispersion by a prism.

two wave lengths,  $\lambda_1$  and  $\lambda_2$ . Since  $\theta_1$  does not equal  $\theta_2$ , the prism has dispersed the two rays. All the dispersed rays of one wave length ( $\lambda_1$ ) emerge from the prism parallel to each other but not to any other wave length ( $\lambda_2$ ). The focusing lens, consequently, will bring each wave length into focus at a different position on the photographic plate and the entering light will have been dispersed according to its component wave lengths.

The dispersion of a quartz prism is not linear; i.e., at wave length 2180 Å, a one millimeter separation of two spectral lines on the photographic plate (of a large Littrow) is equivalent to a wave length difference of 1.54 Å, but, at wave length 3556 Å, a one-millimeter separation of two lines is equivalent to a wave length difference of 7.10 Å. Dispersion is a very important factor in judging the quality of a spectrograph — the greater its power of dispersion, the better the instrument.

Another factor which is very important in determining the quality of a spectrograph is its resolving power. This may be defined as the ability to reveal fine detail in structure, or in terms of spectral lines, it may be regarded as the smallest separation which can exist between a pair of lines while they still appear as two distinct lines. *Resolving power* is expressed mathematically as the ratio of the average wave length of the two lines to the difference in wave length between them, or  $R = \lambda/d\lambda$ .



In prismatic instruments the resolution actually achieved depends upon the slit, prism, and the camera lens. When certain optical conditions are satisfied and incorporated by competent design of the instrument, the resolving power depends upon the length of the base of the prism, as well as its rate of change of refractive index with wave length. In practice, however, the resolution achieved never equals the theoretical maximum since this assumes an infinitely narrow slit, which is a practical impossibility.

### Diffraction Gratings<sup>25</sup>

A relatively extended treatment of diffraction gratings will be given here for two reasons: (a) the phenomenon of dispersion by a grating is generally less well understood than dispersion by a prism, and (b) a few additional paragraphs on the subject here will eliminate the necessity for further discussion in Chapter 42 on x-ray diffraction.

From elementary physics it is learned that the apparent rectilinear propagation of waves is approximately true only for a wave motion in which the wave lengths are very small in relation to the dimensions of ordinary openings or obstacles. The phenomenon of diffraction of light, i.e., its bending or spreading around the edges of obstacles, becomes discernible when small obstacles or openings are used. If monochromatic light of wave length  $5 \times 10^{-5}$  cm falls normally on a distant screen in which there is a pinhole of 1 mm diameter, a second screen at a distance of 10 cm, 16.7 cm, or 50 cm, will show a bright spot of maximum intensity at a point on the axis of the pinhole. At intermediate distances from the pinhole to the screen a dark spot is obtained instead of a bright spot. A similar phenomenon is observed when a small circular obstacle is placed in the path of the light.

Bright and dark areas can be produced on a screen when monochromatic light is permitted to fall on an opaque plate which is marked by a number of narrow, parallel, equidistant openings. Such an arrangement is known as a *transmission grating*. In Fig. 276, monochromatic light from a source  $S$  is rendered parallel by lens  $L_1$ , and falls on a transmission grating  $DD$ . Passing through the apertures, the light waves are diffracted in all directions. Falling on lens  $L_2$  the light converges at points such as  $P$ . To find the resulting amplitude at  $P$  the principles of interference must be applied. The amplitude at point  $P$  will depend on its position. Because of the use of lens  $L_2$  the path difference between any ray in one slit and the corresponding ray in the succeeding slits is always the same. It is sufficient, then, to consider the rays coming from points  $A$  and  $C$ . If their path difference ( $CM$ ,  $EN$ , or  $GR$ ) is exactly one wave length or any integral number of wave lengths, the rays from all such points, i.e.,  $A$ ,  $C$ ,  $E$ ,  $G$ , etc., will be in phase, and a bright maximum will be visible at  $P$  (and also at a point at the same distance on the other side of  $F$ ).

Let  $\theta$ , be the angular separation of  $P_1$ , the first bright maximum. Since  $\angle POF$  and  $\angle CAM$  have mutually perpendicular arms, they are equal; hence

$$\sin \theta = \frac{CM}{AC},$$



and, since

$$\begin{aligned} CM &= \lambda, \\ \lambda &= AC \sin \theta. \end{aligned} \quad (1)$$

If a second bright maximum occurs at a point  $P_2$  for which the angular separation is  $\theta_2$ , we should have

$$2\lambda = AC \sin \theta_2.$$

For the  $n^{\text{th}}$  bright maximum at  $P_n$  we should have

$$n\lambda = AC \sin \theta_n.$$

$AC$ , the width of one aperture and one opaque region, is known as the *grating element*, and is usually designated as  $d$ . Thus, the more general form of the equation is

$$n\lambda = d \sin \theta \quad (2)$$

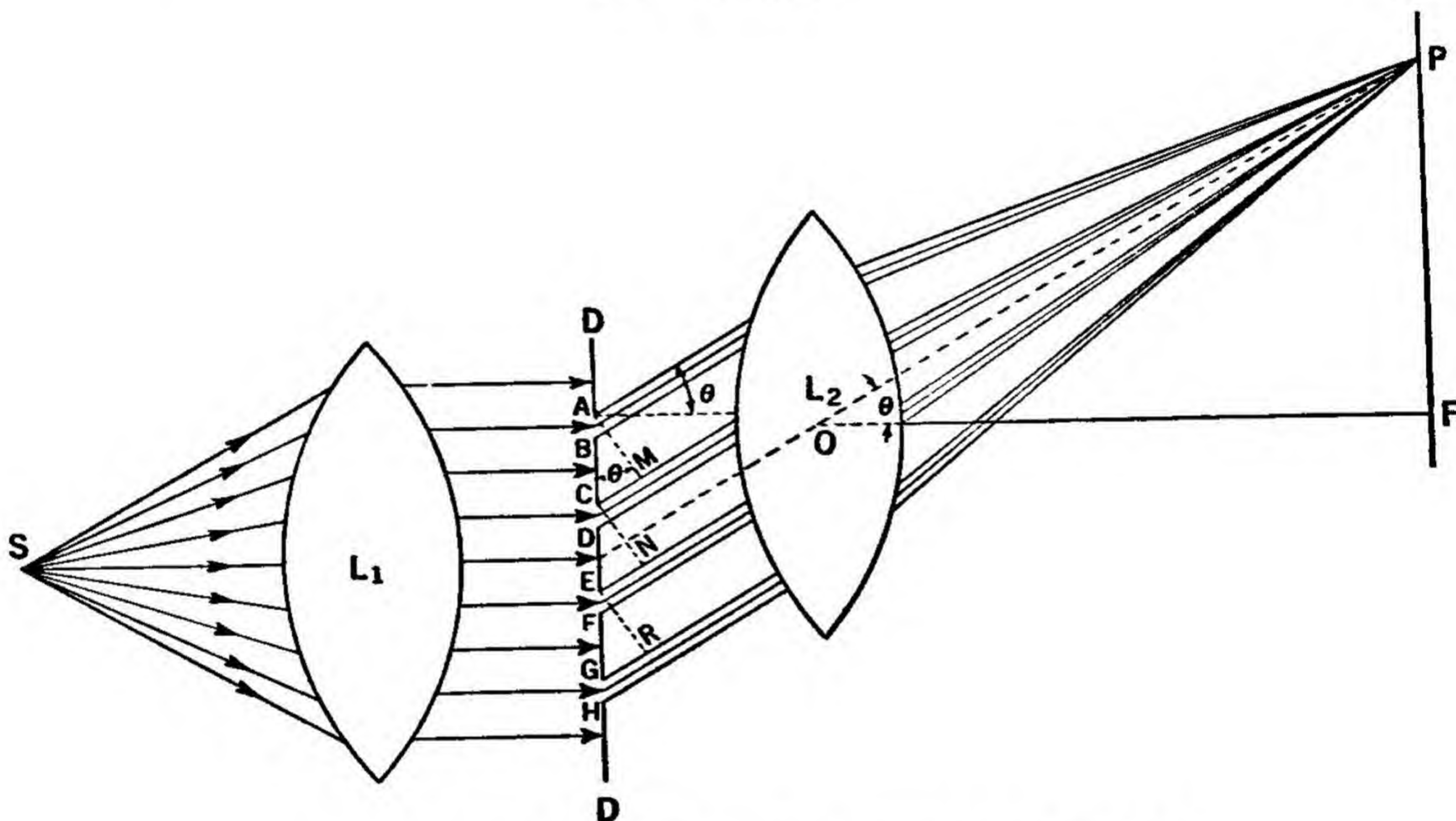


Fig. 276. Diffraction through a transmission grating.

The number  $n$  designates the *order* of the spectrum. When  $n = 1$ , the spectrum is said to be of the first order; etc. The number of orders observable depends upon the width of  $AB$  and  $AC$ . Laboratory transmission gratings usually are ruled so that about 10,000 to 30,000 grating elements per inch are present. With such gratings only two or three orders are visible. The intensity of light does not decrease gradually between one bright maximum and next, but rather falls off sharply so that extremely bright lines are visible, separated by wide dark regions. Another important fact is that the grating spectrum is approximately linear.

If, instead of monochromatic radiation, white light were to fall on the grating, there should be present, according to equation (2), a bright maximum for each wave length. By measuring  $\theta$  for these maxima it is possible to determine  $\lambda$  from equation (2); hence a grating can be used in spectroscopic instruments.



### Dispersion

We have seen that dispersion is defined as  $d\theta/d\lambda$ . Hence from

$$\sin \theta = \frac{n\lambda}{d},$$

we have

$$\frac{d\theta}{d\lambda} = \frac{n}{d \cos \theta}. \quad (3)$$

The dispersion of diffraction gratings, then, increases with the order of the spectrum; also, as the grating element,  $d$ , becomes smaller the dispersion becomes greater. Dispersion is also a function of the wave length, and does not depend upon the index of refraction as in the case of a prism, so that the dispersion of a grating is linear.

### Resolving Power

The value of  $\lambda/d\lambda$  where  $d\lambda$  is the smallest difference in wave length which can be detected is taken as a measure of the resolving power. It can be shown that

$$\frac{\lambda}{d\lambda} = nN, \quad (4)$$

where  $N$  is the total number of grating elements. Hence resolving power increases with the order of the spectrum,  $n$ , and the total number of lines in the grating.

### Reflection Grating

If, instead of passing through a transmission grating, the light is reflected from a polished plane surface which is ruled into many fine parallel lines, it is possible to observe diffraction orders similar to those described above. It can be shown by a similar argument that

$$n\lambda = d(\sin i \pm \sin \theta)$$

where  $i$  is the angle between the incident beam and the normal to the grating, and  $\theta$  is the angle of the reflected beam, the choice of sign depending upon whether or not the incident and reflected beams lie on the same side of the normal. It should be noted that it is not assumed (as before) that the light strikes the grating normally. An equation for reflection gratings will be developed later, when x-ray diffraction is considered.

### Concave Grating

The most important grating used in spectroscopy is a reflection grating ruled on a concave spherical mirror. The great advantage of the concave grating lies in its ability to focus very sharp images without the use of lenses. The absence of lenses makes the concave grating especially effective in the extreme ultraviolet region, where prismatic instruments are not useful because of the absorption by quartz, fluorite, and air.



In Fig. 277,  $DD'$ , the grating, is a segment of a sphere of which  $CF$  is the radius. The circle on which lie points  $P$ ,  $F$ , and  $S$  is drawn with center at  $O$  and radius  $CO = CF/2$ . The geometry of this arrangement is such that when rays from source  $S$  are reflected from successive grating elements at  $A$  and from successive elements at any other point  $B$ , they will come to focus at  $P$ . Hence if

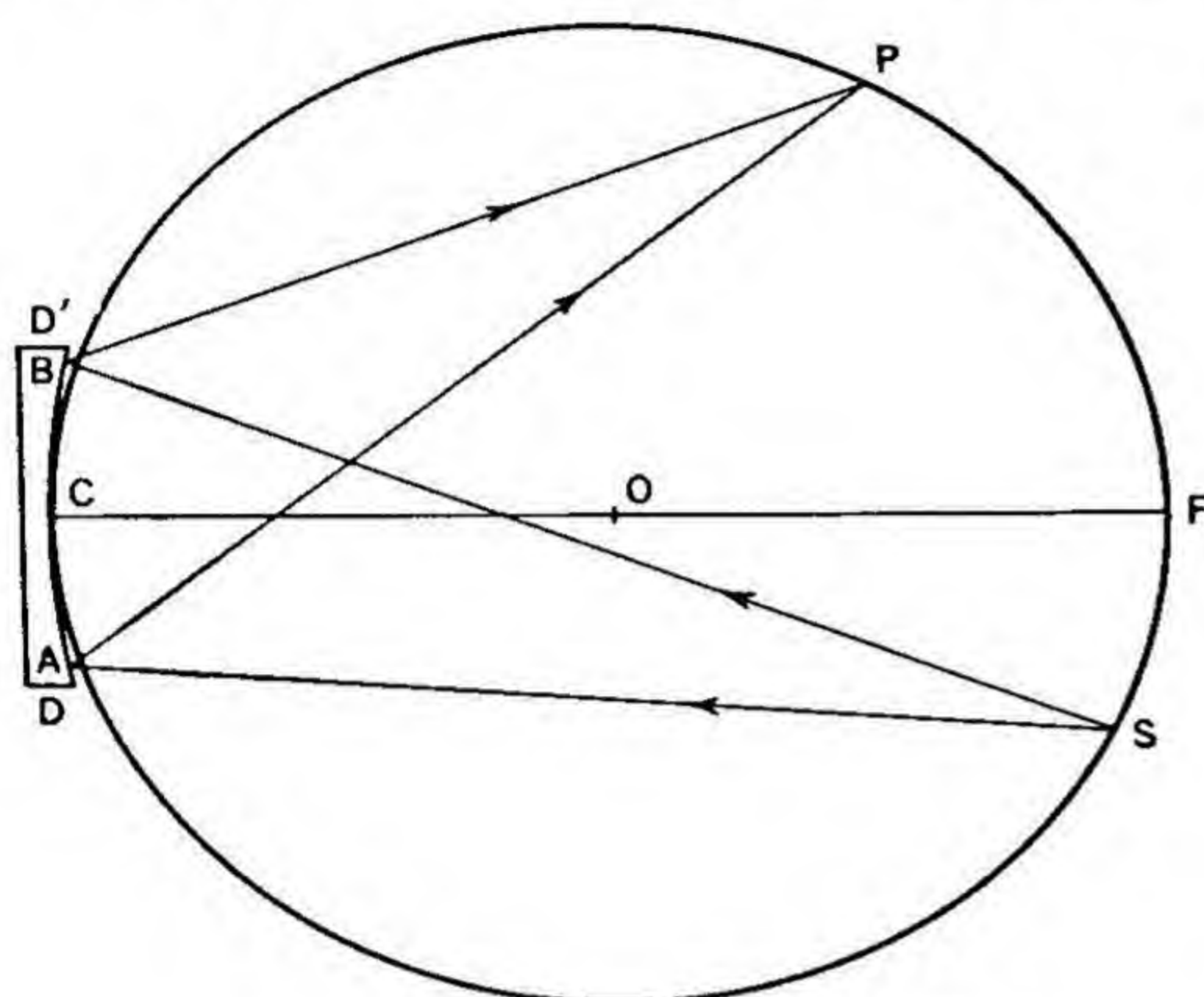


Fig. 277. The concave grating.

a screen is laid along the circle, bright maxima will be observed, corresponding to the various diffraction orders. The rulings on the spherical segment are the projections of equidistant, parallel lines on a plane through  $DD'$ .

## 10. PHOTOGRAPHIC MATERIALS

Only a brief mention of the photographic emulsions employed in spectrographic work will be made here. For additional information the catalogues of the various manufacturers of photographic materials

(Hilger, Ilford, Ansco, and Eastman Kodak<sup>26</sup>) should be consulted.

The following types of Eastman Kodak plates will be suitable for most of the work in a forensic laboratory:

TYPE EMULSION	SPECTRAL SENSITIVITY
Kodak Spectrum Analysis No. 1	
Kodak Spectrum Analysis No. 2	2400-4400 Å
Kodak 103-O	
Kodak 103-F	2400-6800 Å
Kodak III-F	
Kodak I-L	2400-8200 Å
Kodak IV-L	

The type of developer, temperature, developing time, and fixing bath to be used with a particular emulsion are recommended by the manufacturer. It is well to follow these directions closely.

## 11. ADJUSTMENT OF LIGHT SOURCE AND INSTRUMENT FOR FOCUS

In addition to the light source, ( $LS$  — Fig. 274), the adjustable parts of a Littrow type instrument are the diaphragm ( $D_1$ ), slit ( $S$ ), prism ( $P_2$ ), and photographic plate ( $PP$  — Fig. 274). The light source is adjustable horizontally and vertically so that the slit may be fully illuminated. The lens ( $L_1$ ) interposed between the light source and the slit is placed so that the collimating lens



is filled by a cone of light. Care must be taken not to have the incandescent tips of the electrodes focused on the slit opening. The diaphragm ( $D_1$  — Fig. 274) is used to regulate the height of the spectral lines appearing in the spectrogram. The slit ( $S$  — Fig. 274) is opened to the proper width for maximum resolution, but also taking into consideration the exposure time that is permissible before the sample will have been consumed. Thus far, the adjustments were not concerned with bringing into focus that wave length region of the spectrum which it is desired to study.

Wave length settings may be semifixed or variable in a stepwise or continuous fashion. In any case, the wave length setting is accomplished by varying three elements: (a) the focal distance between the slit and collimator lens ( $P_1$  to  $L_2$  — Fig. 274), the latter ( $L_2$ ) being mounted on the same movable platform as the prism ( $P_2$ ) which is at a fixed distance from it; (b) the prism rotation or the angle which the face of the prism makes with parallel rays from collimator ( $L_2$ ); (c) the tilt of the photographic plate ( $PP$ ). In most Littrow-type spectrographs the focal distance and the prism rotation are adjusted by manipulation of a single control which automatically regulates these two factors with respect to each other. It may be necessary that another control be manipulated to regulate the tilt of the photographic plate, although this is also included in the automatic adjustment in many Littrows.

Generally, a table of settings is furnished by the manufacturer for the particular instrument involved, giving the relative positions of prism and photographic plate necessary to cover the entire spectral range of the instrument. In addition a series of test spectrograms taken by the manufacturer on the particular instrument may usually be had; data such as slit width, exposure time, type of photographic emulsion, and position (settings of prism and photographic plate) used are also included with the sample spectrograms. An iron arc is generally employed for these sample spectrograms because it has many lines over the entire spectral region covered by the instrument. The spectrum of iron has been closely investigated and the wave lengths of its spectral lines have been very carefully measured so that they may serve as secondary standards for the determination of the wave length of spectral lines of other elements. This topic will be discussed in detail in the following section.

## 12. MEASUREMENT OF WAVE LENGTHS OF SPECTRAL LINES

Since it is the unique combination of lines at fixed wave lengths which is the basis for the identification of an element by its spectrum, accurate methods must be available for the determination of wave length. The primary standard of wave length is the red cadmium line. Secondary and tertiary standards have been established so that more convenient measurements of wave length may be made.<sup>27</sup> As mentioned above, the iron arc was selected because a pure sample is easily obtained and its spectrum has a large number of lines in the regions which are usually of interest to the analyst. Charts of the iron-arc lines with their wave length values are obtainable (see sec. 17). Thus, the wave length of a



line in the spectrogram of an unknown substance taken in juxtaposition to an iron arc may be determined by interpolation (assuming linear dispersion for small wave length differences) after measuring the distance between two known lines of the iron and the line of the unknown. For example, suppose that an unknown line is between iron lines 2813 and 2851. A measuring magnifier (a magnifying lens arranged to contain a built-in millimeter scale, each mm being divided into tenths) is used to determine the distance of separation between the lines involved. The following calculations are made:

iron line 2851 A	separation distance measured in
iron line 2813 A	millimeters 10.40
38 A	

iron line 2813 A	separation distance measured
unknown line X A	in millimeters 5.47

By proportion:

$$\frac{38}{10.4} = \frac{X}{5.47} \quad \text{or} \quad X = 20 \text{ A}$$

Therefore  $2813 + 20 = 2833 \text{ A} =$  approximate wave length of unknown line.

If greater accuracy is sought, it is necessary to use the Hartmann dispersion formula and a spectrum micrometer comparator when large separation distances are involved, since with prism instruments the dispersion is irrational, i.e., not linear.<sup>28</sup> In certain instruments there is another method which is used to determine the wave length of a spectral line approximately. This consists of reproducing photographically, on the same plate with the spectrogram, a wave length scale which is calibrated for the instrument. The unknown wave length may be obtained from the scale, but the result is considerably less accurate than those described above.

### **Raies Ultimes (Persistent Lines)**

The lines of an element selected for incorporation in spectral line tables are those which disappear last as the concentration of the element in the sample is decreased. These lines, then, may be regarded as the most "persistent" lines of an element or, to use a name given specially to them, *raies ultimes*. They are also known as *letzten linien*, *sensitive lines*, *distinctive lines*, or *principal lines*.

In qualitative analysis it is necessary to identify three or more of the persistent lines of an element to demonstrate its presence in the sample. Contrariwise, if the persistent lines of an element are not found in the spectrogram then the presumption is that the element is not present in the sample.

## **13. METHODS OF QUALITATIVE ANALYSIS**

For the purpose of simplification, consider first the imaginary case in which an unknown substance, upon being examined spectrographically, is found to contain only one metal and no impurities. The identity of this metal is determined in the following manner. After the wave length of one of the more intense



spectral lines in the spectrogram has been determined, a table (see sec. 17) which lists the principal lines of elements by wave lengths is consulted. The possible elements present for the measured wave length ( $\pm 1$  Å) are listed. After three or more lines have been examined the unique arrangement of the spectral lines of one of the elements should be apparent. In other words only one element will appear consistently in the lists of possible elements as each spectral line is examined.

When more complex substances are being examined, as is the usual case in spectrography, two or more possible elements may occur in each of the lists composed from the table of wave lengths for each line studied in the unknown spectrogram. When a situation such as this arises, it is necessary to consult another set of tables which lists by element the principal wave lengths of their respective spectral lines. Unique principal wave lengths of each of the possible elements are selected from these tables, so that at each of the wave lengths chosen only one of the elements will have a spectral line. The spectrogram of the unknown substance is again studied; if the selected spectral lines (of unique wave length) are found in the spectrogram the element may be considered present; those of which the selected, unique lines are not found at the indicated wave length positions are considered to be absent in the unknown specimen.<sup>29</sup>

Instead of measuring the wave lengths of lines, the usual procedure is to make a direct comparison between the spectrogram of the unknown (row *D*,

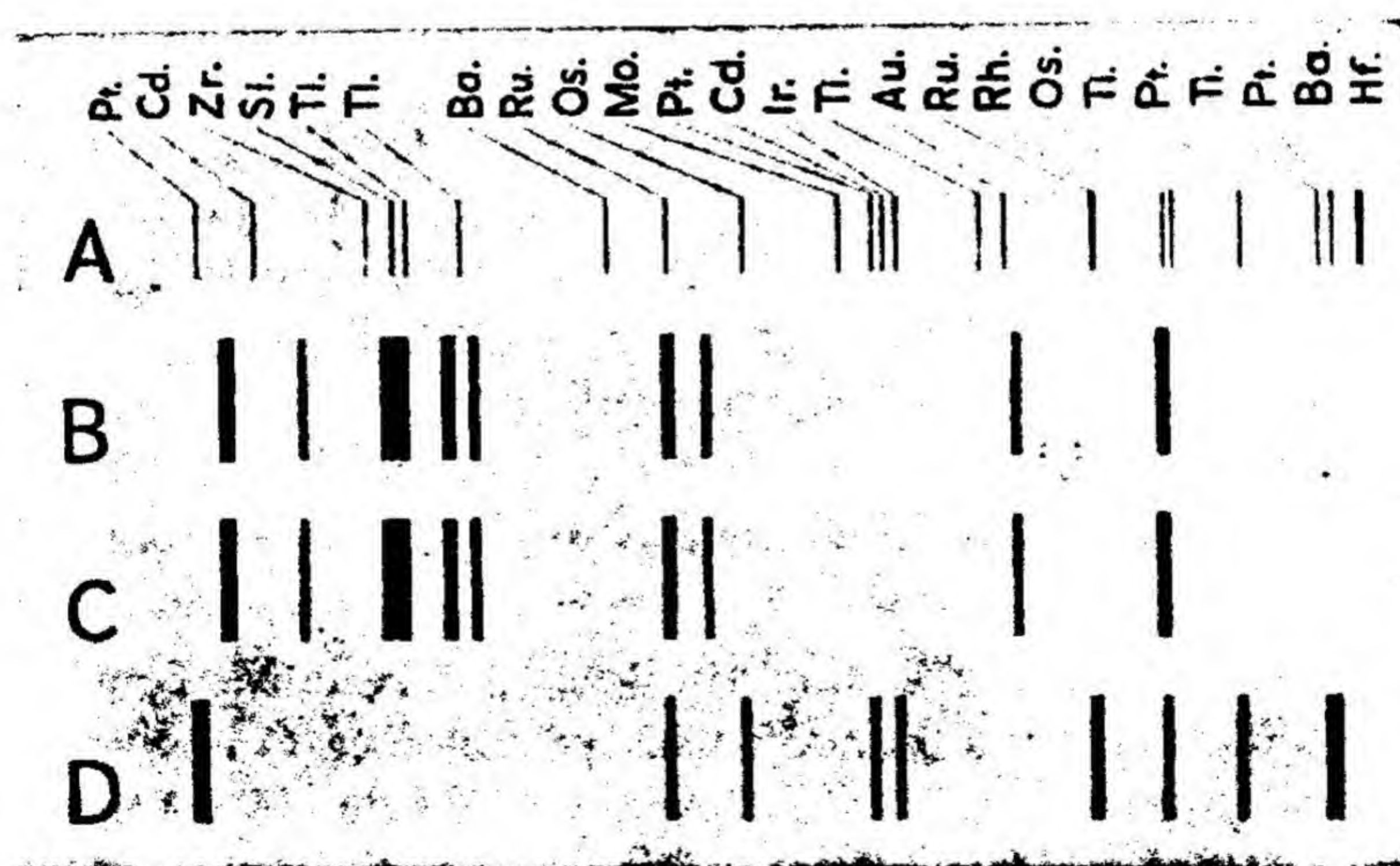


Fig. 278. Comparison of an "unknown" spectrogram with a reference chart.

Fig. 278) taken in juxtaposition of an iron arc (row *C*, Fig. 278) and a series of composite charts which show or indicate the position of the principal lines of the various elements with respect to the iron arc spectrum. Rows *A* and *B* of Fig. 278 represent a portion of such a chart in the region of 2630 Å. All that one need do is to pair off the lines of the iron spectrogram on the composite chart (row *B*, Fig. 278), with the same iron lines (row *C*) on the spectrogram of the



unknown. The elements present in the unknown (row *D*) may be rapidly determined from the composite chart by matching the unknown lines (row *D*) with those shown or indicated on the composite chart (row *A*).

Thus, in most cases, several lines of an element are found and its identity is established. However, if only the most persistent line of an element can be found, the possibilities of interference by other elements must be considered. Tables which indicate the element sought, the wave length of the line interfered with, and the concentration of other elements which may interfere with the identification of the trace element thought to be present on the basis of its persistent line are available.<sup>30, 31</sup>

The foregoing procedures for the identification of spectral lines require considerable time if several elements are present in the sample. However, with

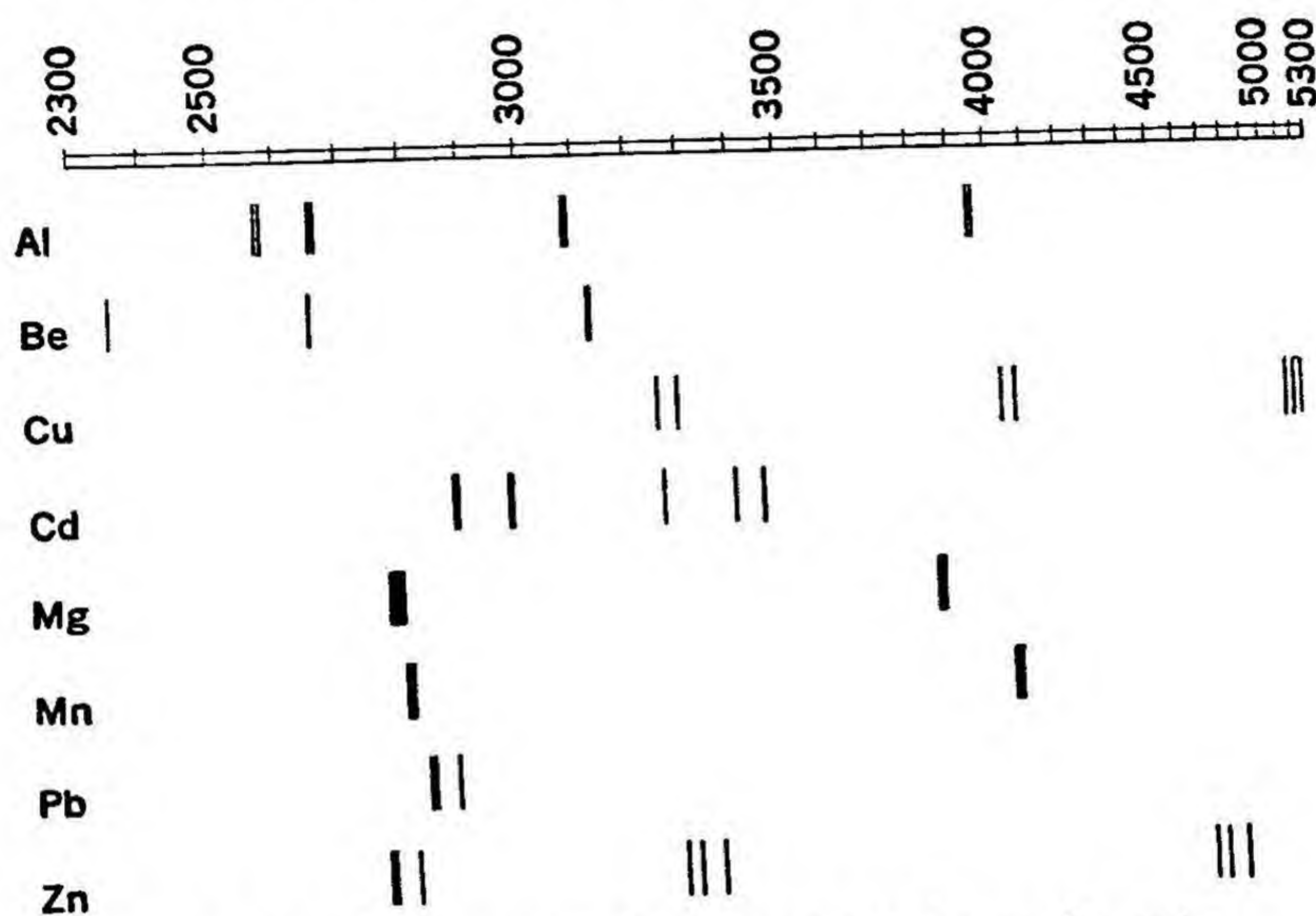


Fig. 279. Characteristic line groupings of some elements.

experience the spectroscopist is able to discern characteristic combinations of the spectral lines of various elements without reference to any scale. By this knowledge he is able to identify many of the elements rapidly merely by inspection. Figure 279 shows some of the more characteristic spectral groupings of a few elements. The wave length scale is appended only to indicate to the reader the region in which these combinations occur.

If any doubt exists as to the constituents of the unknown, it is possible to prepare from chemicals that are *spectrographically pure* a representative sample containing all the elements which are suspected of being present in the unknown. The spectrogram of the prepared sample is made under the same conditions as those which obtained when the spectrogram of the unknown was made. A line for line comparison is then possible between the unknown and the prepared, known samples. If they do not agree the constituents of the latter are changed



until the spectrograms do agree, line for line. This will occur obviously when the same elements are present in both samples in approximately the same quantities. This procedure will seldom be necessary for an experienced spectroscopist.

#### 14. QUANTITATIVE ANALYSIS

The spectrograph is now used extensively in industry for quantitative determinations. Its application in this fashion, however, to the needs of criminalistics is by no means a simple matter. In developing a quantitative method for analysis of a substance by spectrographic means, considerable study is necessary to determine appropriate techniques of preparing the sample and the required conditions of excitation. It is only after thorough investigation that quantitative methods can be simplified sufficiently to permit their routine application. When the sample is known and plentiful in quantity the necessary research is possible; however in the work of criminalistics, where unknown samples of a highly varied nature are submitted in very limited quantities, it is not always possible. In certain cases standardized quantitative procedures that are of interest to forensic investigators have been developed. For example, the use of the spectrograph in the quantitative determination of lead and bismuth in biological specimens, may be found in two articles by Cholak.<sup>32, 33</sup> Hess, Owens, and Reinhardt<sup>34</sup> describe a method for quantitative determination of eleven trace elements in organic materials. However, the method is not necessarily limited to these elements, but may be extended to include many other metals. Furthermore, it is not limited to organic materials, since the sample that is analyzed is actually a solution of inorganic salts. Accurate analyses are possible in spite of considerable differences in the extraneous composition of the sample, because a spectroscopic buffer, sodium nitrate, is used to eliminate this effect. Only two internal control elements, bismuth and molybdenum, are required. A high-voltage, alternating-current arc (sec. 4) is used as the light source. Considerable work, of course, is required before the empirical curves to be used in actual analyses are obtained.

In certain cases where there is sufficient sample another approach for obtaining quantitative results may be employed. The basis of this approach lies in the use of organic reagents that form highly colored compounds even with traces of metals.

Colorimetric analysis almost rivals the spectrograph in sensitivity, and is peculiarly applicable to spectrographic cases where quantitative determinations would be helpful. The great difficulty in using colorimetric methods with unknown substances lies in the interference caused by other elements which also react with the organic reagent. In spectrographic cases, however, a complete qualitative analysis is available, so that the presence of any interfering elements is known to the analyst.

In general, the methods in Sandell<sup>35</sup> or Mellan<sup>36</sup> may be employed when there is sufficient sample and when there are no interfering elements present. If any are present, it may be possible to eliminate them by adjustment of  $pH$ , or by the techniques suggested in the literature in this connection. Letonoff and



Reinhold<sup>37</sup> have described a method which is useful for colorimetric determinations of lead in blood, tissues, excreta, and foods.

It should be pointed out that the greatest value of quantitative determinations in forensic spectrographic work is in their ability to help resolve doubts in borderline cases. If the number of trace elements is not large or not too unusual, the spectrographer may wish to confirm any judgment of a unique origin of the unknown and known samples by quantitative determinations (see sec. 19). Quantitative agreement in the amounts of certain elements would obviously, increase the accuracy of his judgment.

## 15. ABSORPTION SPECTRA

Although the applications of absorption spectra — or, more properly, absorption spectrophotometry — to criminalistics are discussed in Chapter 43, it should be pointed out that the spectrograph may also be used for this purpose. In particular, mention should be made of the ability of the spectrograph to enable absorption studies to be made in the ultraviolet. It is beyond the scope of this text to discuss the methods or techniques employed. An excellent treatment of this subject has been given by Twyman and Allsop.<sup>38</sup>

The use of the absorption spectrum of carboxyhemoglobin for the detection of carbon monoxide in blood is discussed by Hawk and Bergheim.<sup>39</sup> An absorption method that may be used for quantitative determinations of the different hemoglobin compounds in blood serum is described in an article by Owens.<sup>40</sup>

## 16. GENERAL PROCEDURE

The usual procedure required in forensic spectroscopy is to compare two samples with each other. Quite frequently one sample, generally the unknown, is rather limited in quantity, but the other sample, usually the known, is available in larger quantities. Therefore, the preparation of the specimen and the selection of the other conditions (i.e., wave length setting of the instrument, type of film required, exposure time, etc.) are determined by using the larger sample first. When the quantity of one of the samples is very small, it is necessary to employ conditions of maximum sensitivity. In these cases, it is advisable to consider using the cathode layer or moving plate method of analysis. After these preliminary determinations have been made, the conditions most suitable for the examination of the unknown sample are selected. Two spectrograms are made in juxtaposition; one of the known, another of the unknown. By this procedure all of the smaller sample, if necessary, may be used profitably in making the comparison spectrogram.

The wave length region from 2300–7000 Å will be found to be most useful for analysis of a specimen of unknown composition. With large spectrographs it requires more than one setting of the instrument to cover this range. Obviously, the setting selected for the examination of a sample that is limited in quantity will be that in which the largest number of lines of the elements are found. In general the region from 2400 to 3400 Å is most useful. In the handling of small



samples which are to be examined spectrographically, it will be found both convenient and suitable to use the apparatus and manipulative techniques developed for analytical work on the semimicro and micro scale.<sup>41-45</sup>

### Preparation of Sample

When a specimen is to be analyzed by arc methods it is generally necessary to prepare the sample before it is placed in the crater of the lower electrode; otherwise, the conditions for arcing may not be satisfactory. The main difficulty that is encountered, if the specimen is not prepared properly, is loss of the sample before a representative spectrogram is obtained. For example, compounds containing water of crystallization sometimes lose the water so rapidly at the temperature of the electrodes that the sample is lifted physically out of the cavity. Compounds that volatilize easily or decompose with the evolution of gases at the temperature of the electrodes may be expected to behave in similar fashion. Compounds that are difficult to volatilize may melt and the molten sample may be rocked out of the crater owing to the wandering of the arc. Metal samples unprepared for arcing may spit, sputter, and form oxides that interfere with the stability of the arc.

These difficulties are by no means insurmountable. Preliminary heating of the sample is employed to decompose unstable compounds and to eliminate water of crystallization. Chemical treatment designed to convert the original sample into a form more suitable for arcing is also used. In general, however, these techniques are not used frequently in forensic spectrographic work because of the limited sample, the danger of losing trace elements of low volatility, and the possibility of contamination.

Another technique that may be employed to minimize arcing difficulties consists of mixing the sample with a volatile substance which helps to carry it into the arc. Chemical reducing agents may be used on difficultly volatile compounds such as oxides. The easy volatility of ammonium salts makes them suitable for the former purpose, while powdered graphite is employed for the latter. Since the powdered graphite technique tends to prevent loss of specimen by sputtering or spraying, it is advisable in forensic spectrographic work to prepare the sample for arcing in the following manner:

Powder the specimen to a fineness equivalent to about 200 mesh. In the case of substances such as nonconducting solids this may be done in an agate mortar. Using the powdered unknown, prepare an intimate mixture with graphite, consisting of a minimum of two parts powdered graphite by weight to one part of the unknown. Place from 5 to 20 mg of this preparation in the crater of the lower, positive electrode. The arc is now ready to be struck. An arc current starting at 4 amperes and increasing to 10 or 15 amperes, as the more volatile constituents pass off, is usually employed.

Although rarely required in forensic work, solutions as well as powders may, be analyzed in the direct current arc. First, the crater of the lower electrode is impregnated with a drop of kerosene to prevent loss of sample by absorption. Powdered graphite is then added to the crater. Next, 0.5 to 2.0 ml of solution



are placed in the electrode cavity and the solvent is removed by evaporation in a carefully heated oven. Precautions must be rigidly observed to prevent contamination of the sample during the drying process. If sufficient sample is available, it is better to evaporate a portion of the solution; the residue may then be examined in the manner described above.

### Ashing Procedure for Organic Materials

Occasionally, organic materials are submitted to be examined spectrographically for trace elements. For example, in a case involving poisoned candy it would be valuable to know if it contained all the trace elements which were in the sample of poison removed from a suspect's house. In other cases, the detection of the presence of a particular element may be especially desired. Thus, in a homicide case in which a lead pipe was used it would be of considerable assistance in the investigation to learn that the human matter and bone scrapings removed from the skull contained lead and all the trace elements present in the lead pipe found in the possession of a suspect. In these instances, maximum sensitivity of detection is required so that it is necessary to remove the organic material by wet-ashing with spectrographically pure sulfuric, nitric, and perchloric acids. Wet methods are used because the heat of a muffle furnace may cause the loss of volatile elements such as mercury and cadmium.

The ashing procedure is as follows: A sample of 400 to 700 mg (or larger) is placed in a Pyrex test tube or a 20-ml Kjeldahl flask. One ml of concentrated sulfuric acid (spectrographically pure) is added to the tube which is then heated over a sand bath. When charring is complete (this usually takes from 5 to 10 min), a few tenths of a milliliter of concentrated nitric acid (spectrographically pure) is added to the tube or flask and the heating is continued. Nitric acid is added until the oxidation is complete; this is indicated by the solution becoming water-clear. If 1 to 2 ml of nitric acid fail to discharge all the dark coloration, the sample requires stronger oxidation conditions. In this case a few tenths of a milliliter of concentrated perchloric acid\* (spectrographically pure) is added until oxidation is complete, as indicated by the solution turning water-clear. Heating is continued until the liquids have been completely removed. The elements are now present in the form of sulfates. The residue may now be mixed with graphite powder and analyzed in the usual manner.

For quantitative work, however, it has been found that it is necessary to convert the sulfates into nitrates since the latter permit a wide variation in the composition of the original sample without influencing the quantitative results; whereas the results obtained using the former were influenced by the extraneous composition of the sample.<sup>46</sup>

\* Perchloric acid is quite explosive under certain conditions. Anyone working with this compound should be familiar with its properties and the necessary precautions required for its safe handling and use. In this connection, the Manufacturing Chemists Assn., Wash. 5, D. C., have published a *Chemical Safety Data Sheet* (SD-11) entitled "Perchloric Acid Solution." The following references will also be found illuminating: *Chem. Z.*, **66**, 415 (1942); *Chem. Zentr.*, **I**, 1361 (1943); *Z. anal. Chem.*, **107**, 385 (1936).



## 17. REFERENCE LITERATURE: TABLES AND CHARTS<sup>47, 48</sup>

Mention has been made previously of various charts and tables which are used in the interpretation of a spectrogram and the identification of the elements present. Since the spectral lines of iron are used as a reference standard, many charts are available to identify them by wave length. Among the charts available are the following:

*Hilger Charts* (A. Hilger, Ltd., London, 1937). A set of eight enlarged, mounted photographs of the arc spectra of iron (quartz prism dispersion) with the wave length of practically every line indicated. These charts cover the region 2084 Å–10216 Å.

For qualitative work, however, it is more convenient to have the principal or most sensitive lines of the elements indicated or shown in juxtaposition to the iron reference lines (see Fig. 278). Among the available charts of this type are the following:

Brode, W. R., *Chemical Spectroscopy*, 2nd ed., Wiley, New York, 1943.

This book contains a set of thirty-five charts (prism dispersion), covering the arc spectrum of iron from 2310 Å to 5081 Å.

Bardet, J., *Atlas de Spectre d'arc*, Doin, Paris, 1926. Fifty-four charts are available in this work.

Two types of tables are necessary: one listing by wave length the principal lines of all the elements, the other listing the principal lines by elements. Abridged and extended tables of this sort are available. Again, Brode will serve as an example of a condensed set of tables. An example of a more extended table which lists most of the principal lines is:

Harrison, G. R., *M.I.T. Wave length Tables*, Wiley, New York, 1939.

The charts and tables mentioned above, or ones similar to them, should be at hand for reference purposes in a spectrographic laboratory.

## 18. PERSONNEL

Because of the responsibility and sound judgment required of the spectroscopist in a police laboratory and also because the type of clue materials submitted may vary so widely that the work seldom may be regarded as purely routine, it is advisable to employ a trained chemist or physicist for this position. The interpretation of a qualitative spectrogram is not an easy task and the value of the results varies directly with the experience of the individual employed in this position. It is to be expected that he will be familiar with the principal lines of the more common elements; that he will be thoroughly acquainted with the iron spectrum; that he will have extensive knowledge of the sources of raw materials and of the typical composition of a wide variety of substances, both manufactured and natural. In his hands the following advantages may reasonably be expected from the investment in spectrographic equipment.



A small sample, i.e., a few milligrams, may be analyzed rapidly with great sensitivity in the detection of even the impurities or trace elements, without regard for the ease or difficulty of the ordinary determination and separation of the elements present by the usual chemical methods. In addition, experimental and personal errors are reduced to a minimum and a permanent record of the composition of the evidence sample is obtained in the form of a spectrogram. This may later be examined by opposing experts or used to prepare enlarged positive spectrograms as evidence for exhibit in court.

## 19. PROBATIVE VALUE OF SPECTROCHEMICAL ANALYSES <sup>49</sup>

A considerable portion of the work of the spectroscopist in a police laboratory consists of making a comparison of the spectrogram of an unknown with that of a known. For example, when a jimmy, suspected of having been used in a burglary, is submitted to the laboratory together with paint scrapings from a window or door, it is first necessary to compare the respective spectrograms of the paint on the jimmy with that of the paint from the window or door of the burglarized house. Obviously, they should be the same if the burglar's tool is to be connected with the crime. On the other hand a mere comparison of the spectrograms is not sufficient; it is also necessary to identify the elements present.

For the sake of discussion let us suppose that two paint spectrograms match line for line, but that, when the qualitative identification is completed it is found that only those elements ordinarily found in these paint types are present. In this case would the findings of the forensic spectroscopist justify a claim that the paint on the jimmy came from the paint of the window? The answers to questions such as this are not simple. For example, if an element, present perhaps only in small quantities, i.e. as a trace, is identified in both samples and this element is not usually associated with paints, then it would be correct to argue a common origin for the two paints. Another alternative which must be considered is the case of two paints (known and unknown) which have in addition to the usual constituents, small but numerous and not particularly unusual, traces of contaminating foreign elements which frequently are present in the raw materials or are picked up during the routine processing of the paint in the various stages of its manufacture. The question arises — what is the minimum number of such trace elements which need be present to “confer uniqueness” on the two samples? The answer of course must be somewhat arbitrary. If there are available sufficient data concerning the statistical variations of these constituents in paints, an answer based on probability considerations may be had (Chap. 46). The usual procedure at present is to accept the judgment of the spectroscopist. As in the case cited above, he will declare two paints to be similar if the spectrograms are the same and some trace element if it is very unusual (or several trace elements if they are more common as contaminants) is present. Obviously, sound judgment and familiarity with the spectrographic composition of paints (in lieu of accurate compilations of the statistical variations in the composition of paints) is necessary in making decisions of this kind.



If a common type of paint such as a white lead-lithopone mixture is found on a screw driver or wood chisel the evidentiary value is not very great. However, if the paint is located on a table knife, pair of scissors, or fingernail file, the value as evidence is considerably greater because of the infrequency of paint on these articles. In the case of the screw driver it would be necessary to find several trace elements in both paints (as many as thirty have been found in some samples) before any claim for uniqueness could be made. If two different paints are involved, as might happen in an automobile accident, such as between a bicycle and car, or two cars in which both paints are simultaneously transferred, the evidentiary value is increased even though a large number of common trace elements or a few unusual trace elements were not found. Again, if the paint is a relatively rare type, such as one which used mercuric sulfide as a red pigment (English vermilion) or zirconium oxide as a white pigment, the value of the clue material as evidence is increased because of the relatively uncommon occurrence of these substances as pigments. For the more common types of paint it would be necessary to find several of the same trace elements in both or a few of the more uncommon trace elements before the spectroscopist would be justified in stating that the two paints had a common origin. Of course other findings less spectacular than that of two samples having the same, unique composition are by no means worthless. Indeed, the mere similarity between two samples of paint, even though only a moderate probability can be assigned to their having come from the same window, when considered not by itself but as a part of a chain of events, may — because the product of the probabilities is involved — be sufficient to throw the scale of doubt beyond that which is reasonable.

As another example of a common clue material that is suitable for spectrographic analysis, let us consider soil. In the case of this material, a large volume of spectrographic data relative to trace elements has been accumulated by various governmental agricultural experiment stations whose interest arises out of the importance of these elements in plant and animal nutrition.<sup>50, 51</sup>

The earth's crust is of fairly uniform composition, 98 per cent consisting of only twelve elements. Of these twelve, eight may be analyzed spectrographically, although in the case of these "macro" elements (silicon, aluminum, iron, calcium, sodium, potassium, magnesium, and titanium) ordinary chemical methods may be used. The remainder of the elements makes up the other 2 per cent of the earth's crust and constitute "micro" or trace elements; in criminalistics, trace elements are of considerable interest in the examination of the evidence and comparison samples.

Rogers, et al.,<sup>52</sup> in a study of 89 cultivated and 43 virgin soils from 77 different locations in peninsular Florida reports on the distribution of 27 micro (trace) elements as determined spectrographically. These results are shown in Table 30.

Of the twelve trace elements in the first three columns, eleven are reported by Souder<sup>53</sup> as having been found in six soils taken from three geographically different sections of the country (Texas, California, and Maine — two samples were obtained from each state); the samples were taken from the same field within 100 ft of each other but they were different in physical appearance. Only



one of the elements in the last column, cobalt, is listed as having been found in the soils from Texas and California; in the Maine soil, cobalt was found in one sample but not in the other.

From these studies it can be seen that, in general, spectrograms of widely different soils will be quite similar. Souder,<sup>54</sup> quite properly, admonishes against hastily concluding that this similarity may be interpreted as indicating a common origin for the soils. Instead, the factors upon which an experienced spectroscopist should base his conclusions that the soils are the same are the absence of minor differences, such as a few lines in one spectrogram which are not present in the other, and the absence of variations in the relative intensities of the lines

TABLE 30

DETECTED IN PRACTICALLY ALL SAMPLES	DETECTED FREQUENTLY	DETECTED IN A FEW SAMPLES	NOT DETECTED IN ANY SAMPLE
Titanium Copper Boron Zinc	Strontium Barium Chromium Manganese Zirconium	Nickel Silver Vanadium Lead	Arsenic Antimony Bismuth Cadmium Thallium Cobalt Tin Molybdenum Lithium Caesium Yttrium Tungsten Lanthanum Beryllium

of the elements present. In addition, the number and type of trace elements must be considered, especially those found in columns 3 and 4 of Table 30.

Glass fragments are another type of clue material which is submitted to the laboratory for spectrographic analysis. Usually, a comparison is requested between the fragments remaining at the scene of the crime with those found in the possession of the perpetrator. In a hit-and-run case by an automobile the known sample is not found at the scene but rather it consists of the pieces remaining in the broken headlight lamp, whereas if window glass is broken, as in some burglary cases, the known sample is found at the scene. Generally speaking, the spectrograph is of greatest value in these cases in demonstrating major differences in composition between two samples rather than in proving them to be the same, for there frequently is no great variation in the ultimate composition of glasses used for the same purpose. Of course, if some unusual trace element should be present the same type of reasoning applies, as in the case of the soil materials or paints discussed above.



## EXERCISES

1. It is highly recommended that the student perform all the appropriate experiments found in Gibb<sup>55</sup> and the more extended exercises found in Brode.<sup>56</sup>
2. After these exercises have been mastered, several samples of typical clue materials such as paints, soils, glass, metals, etc., should be collected. These samples should be chosen from widely different sources but, at the same time, they should appear to be similar to the unaided eye. For example, several white paint samples may be found which, to the eye, appear to be similar; likewise, glass from several auto headlight lenses (i.e., from different cars of the same make, year, and model) should also be obtained. Spectrographic analyses, using the appropriate techniques, should be made of these substances. Since these substances are apparently similar, the results should be compared for the similarities or differences which are revealed in the spectrograms; particular attention should be paid to the variations found in each type of clue material examined. It would be well also to make a comparison between two or three samples of paint taken, as would be the case in obtaining a known sample in a burglary investigation involving paint on a jimmy, from different areas on a window or door which might have been forced in the commission of the crime.

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# **PART I**

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## **ADVANCED INSTRUMENTAL METHODS OF ANALYSIS**







# CHAPTER 42

## X-RAY DIFFRACTION

### 1. ANALYSIS BY X-RAY DIFFRACTION

The most powerful tool available to the scientific criminologist for the analysis of small traces is, as we have seen, the spectrograph. With this instrument the chemical composition of minute samples of clue material can be determined. The spectrograph accomplishes this analysis by revealing the metallic elements present in a substance. It does not, however, indicate the crystal structure or the nature of the molecule present. Such knowledge may at times be of critical importance. It is for this reason that x-ray diffraction apparatus should occupy a position in the police laboratory at the side of the spectrograph: it is capable of analyses which are beyond the power of the spectrograph, and it provides a valuable supplement to spectrographic analyses. In addition, the x-ray diffraction analysis does not destroy any part of the sample used; hence the evidence can be preserved even though it is only a minute scraping of paint. The method is most effective in the analysis of crystalline substances; it will, however, also reveal valuable information concerning an amorphous substance such as glass.

The method of x-ray diffraction consists in sending a narrow beam of x-rays through the crystals of a substance and recording photographically the manner in which the crystal diffracts the rays. In this way the crystal structure of the substance is determined. The nature of the substance also is revealed because crystal structure is a unique characteristic. The application of this information to the work of the criminalistician will be discussed at the end of this chapter. For an appreciation of the possibilities of x-ray diffraction an elementary knowledge of the theory is necessary.

### 2. THE CRYSTAL AS A DIFFRACTION GRATING

In Chapter 41 we saw that, when light passes through apertures which are of the order of magnitude of the wave length of light or is reflected by a ruled surface, the phenomenon of diffraction is observable. Each aperture serves as a source of a new wave front, and the resulting disturbances on a screen or photographic plate reveal very bright maxima where they are in phase, sepa-



rated by dark bands where they are out of phase. For first order diffraction the following relation was derived:

$$\sin \theta = \frac{\lambda}{d}, \quad (1)$$

where  $\theta$  is the angular width of the central band;  $\lambda$  is the wave length of the light used; and  $d$  is the grating constant. Since  $\theta$  and  $d$  can be measured fairly accurately, the wave length of light can be determined.

X-rays are electromagnetic waves of the same nature as light. They differ only in wave length,  $\lambda$  for x-rays lying between 500 Å to 0.06 Å. It would be expected that they would exhibit the phenomenon of diffraction if the grating used were sufficiently fine. In optical diffraction the gratings employed are ruled with approximately  $10^4$  lines per centimeter, so that  $d$ , the grating element, is about  $10^{-4}$  cm or  $10^4$  Å in width. If we assume 1 Å as the average wave length of x-rays and 5000 Å for light waves, then since a grating element of 10,000 Å is required for optical diffraction, we can conclude that a grating element of 2 Å or  $2 \times 10^{-8}$  cm would be required for the diffraction of x-rays.

The mechanical ruling of such a fine grating is practically impossible. Nature itself, however, provides an ideal grating in the regular arrangement of atoms in the lattices of crystals. From the density of a substance such as rock salt and from Avogadro's number we can deduce that the distance between atoms along the edge of the crystal is about  $2.8 \times 10^{-8}$  cm. This number corresponds ideally to the specifications for our x-ray diffraction grating.

In optical diffraction we know the value of the grating constant and can determine by means of equation (1) the wave length of light. In x-ray diffraction we have the opposite problem: knowing the wave length of the radiation, to determine the grating constant. This grating constant is characteristic of the crystal under examination and hence can be used to identify the substance.

### 3. CRYSTAL STRUCTURE

A crystal is a homogeneous and anisotropic solid medium resulting from orderly arrangement of the constituent atoms. Under suitable conditions all crystals can develop crystal faces. The angle between corresponding crystal planes is constant, and the relative orientation of crystal faces is a characteristic property which may serve to identify the crystal. In order to describe the crystal planes an appropriate coordinate system must be chosen. The planes can then be indexed in terms of their intercepts on the coordinate axes. The axes are usually chosen parallel to certain crystal edges and are not necessarily mutually orthogonal as in Fig. 280. Moreover, it is found useful to work with different unit lengths on each of the axes. In Fig. 280 the equation of the plane may be written as

$$hx + ky + lz = p$$

where only the ratios  $h : k : l$  and the ratios of the unit lengths are significant, since the constant  $p$  identifies only one of the planes of the set. The intercepts of the plane on the axes are  $a$ ,  $b$ , and  $c$ . It can be seen from elementary geometry



that the constants  $h$ ,  $k$ , and  $l$  are proportional to the reciprocal intercepts  $1/a$ ,  $1/b$ , and  $1/c$ . The constants  $h$ ,  $k$ , and  $l$  are called the *indices* of the plane and are written as a triad, viz.  $(h\ k\ l)$ . It will be found that the indices of any crystal face are proportional to three small integers when the axes are chosen in the manner described above. These three integers (without a common factor) are called the

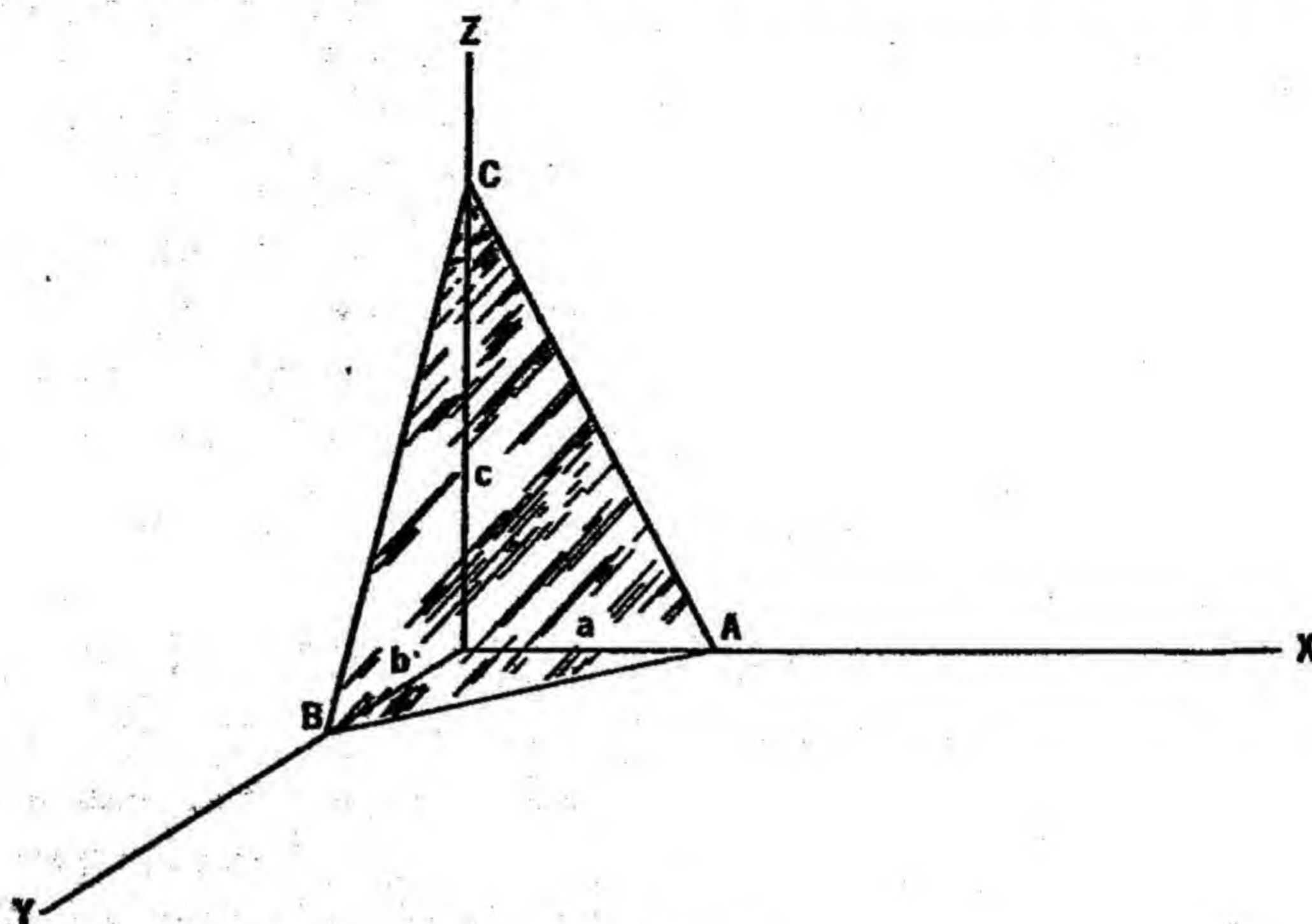


Fig. 280.

*Miller indices.* Thus, the expression  $(010)$  would represent a plane intersecting the  $Y$  axis at unit distance and parallel to the  $X$  and  $Z$  axes; its intercepts would be  $\infty, 1, \infty$ .

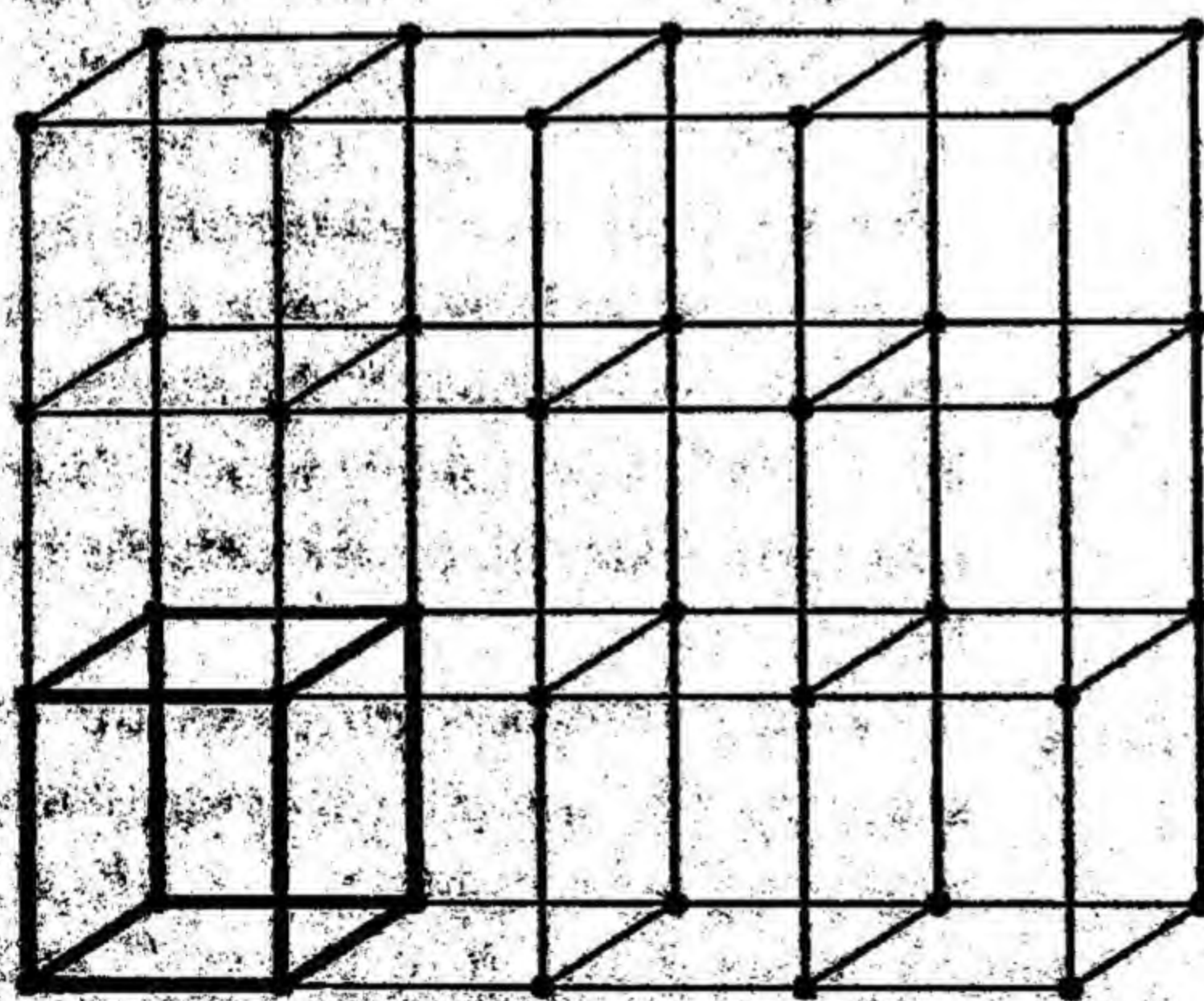


Fig. 281. Space lattice and unit cell.

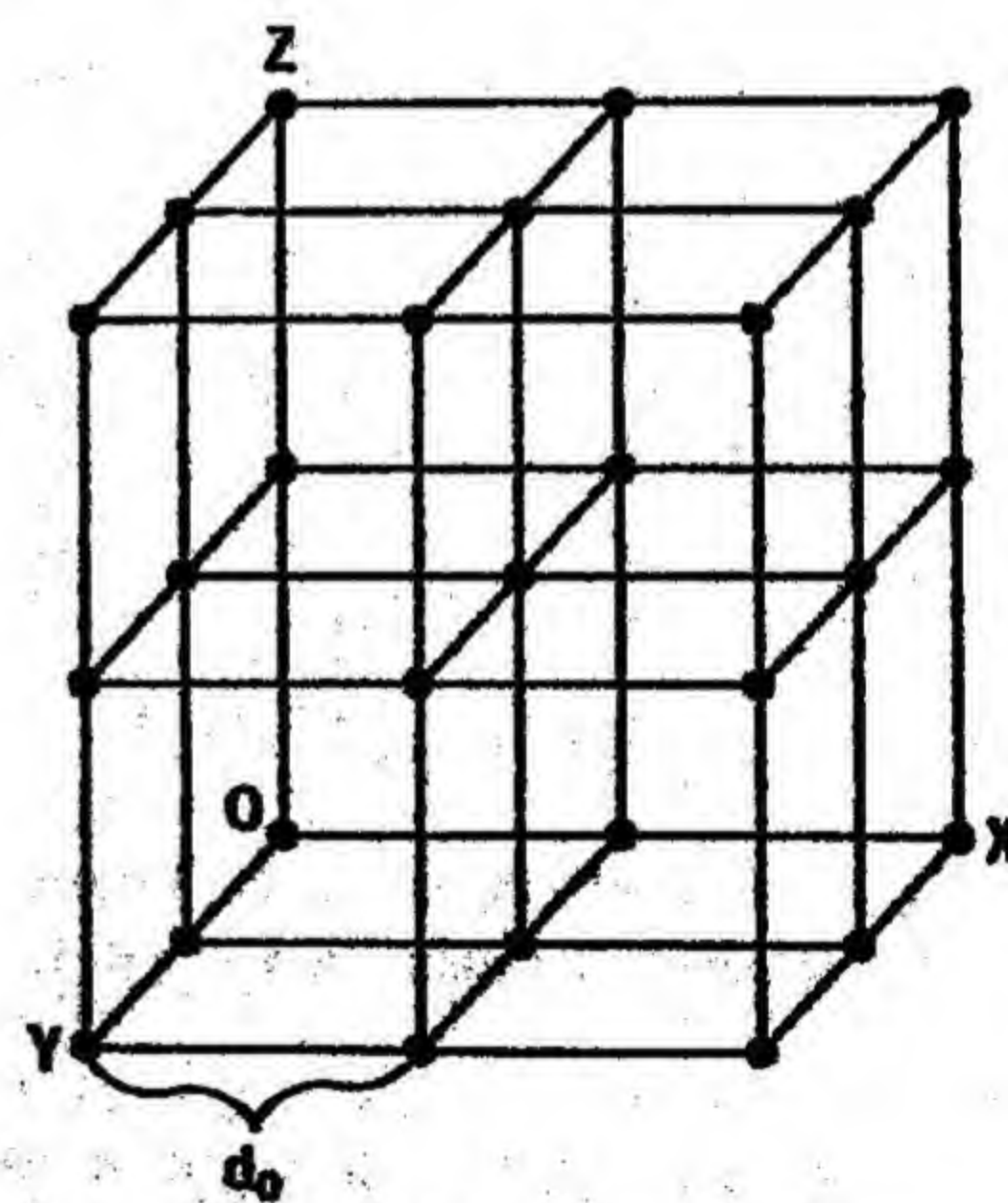


Fig. 282. NaCl crystal.

The various indices and angles of crystal faces can be explained by six coordinate systems, which give rise to six crystal systems: triclinic, monoclinic, orthorhombic, tetragonal, hexagonal (including rhombohedral), and cubic. In studying these systems the common concept of unit cell and space lattice is employed. The unit cell is the smallest volume element which possesses all the



properties of the macrocrystal. The crystal lattice in Fig. 281 is obtained by subjecting the unit cell (heavy-lined parallelopiped) to all of a prescribed set of operations called a *translation group*. Thus all the interplanar spacings of the crystal can be expressed in terms of the unit cell.

In Fig. 282 a cubic lattice (NaCl) is represented. The dimension  $d_0$  of the unit cell will give us information concerning all the interplanar spacings in the crystal. If we refer to  $d_0$  as  $d_{100}$  since it measures the distance between the (100) planes, other interplanar spacings such as those of the (110) and (111) planes may be represented by  $d_{110}$  and  $d_{111}$ . Simple geometry will yield the ratios  $d_{110}/d_{100} = 1/\sqrt{2}$  and  $d_{111}/d_{100} = 1/\sqrt{3}$ . Similar ratios can be readily derived for the (211), (310), (321), and other planes. Thus, a knowledge of  $d_0$  will yield the essential information concerning the crystal. We may consider  $d_0$  as the grating space, and the determination of its value as the immediate object of an x-ray diffraction analysis.

#### 4. BRAGG'S LAW

One of the main differences between the optical diffraction grating and the crystal employed as an x-ray diffraction grating is that the latter is a three-dimensional grating and as such presents a much more complicated state of affairs mathematically. The problem can, however, be simplified by considering the x-rays as being reflected from the various layers. Figure 283 represents a plane section of a crystal. Planes can be drawn through the atoms in many directions, viz.,  $AA'$ ,  $BB'$ ,  $CC'$ ,  $DD'$ ,  $EE'$ , etc. An entering beam of homogeneous x-rays is partially reflected from each of these planes as shown in the diagram. The conditions under which these reflections take place are defined by Bragg's law.

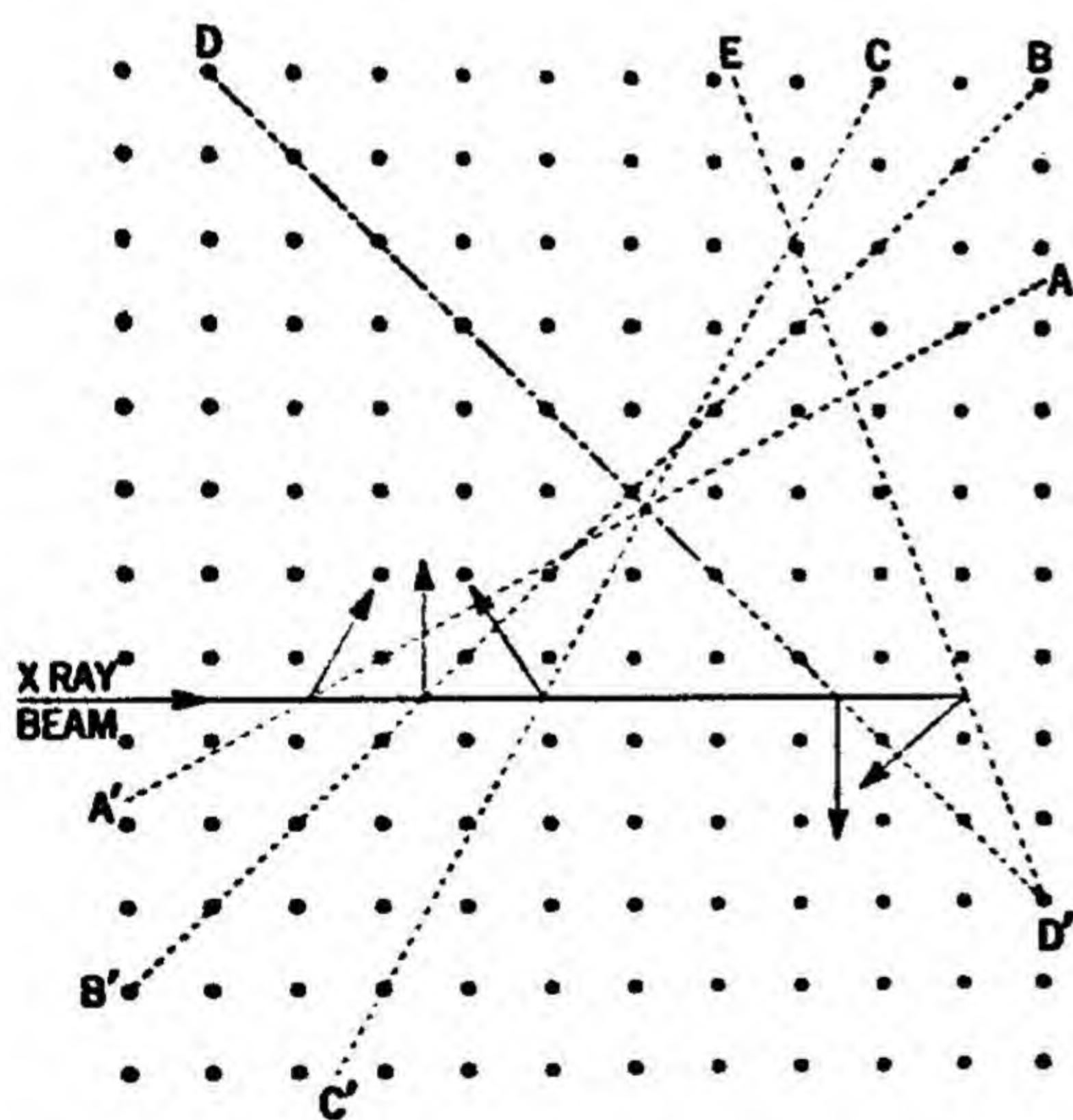


Fig. 283. Reflection of a beam of x-rays from planes of atoms in a crystal.

and  $B_2$  are two beams of x-rays incident at points  $O$  and  $R$  of planes  $L_1$  and  $L_2$ , respectively, at the glancing angle  $\theta$ .  $B_1$  and  $B_2$  are reflected as  $R_1$  and  $R_2$  at the same angle. Draw  $OP$  and  $OQ$  perpendicular to  $B_2R$  and  $RR_2$  at  $P$  and  $Q$  respectively. Since angles  $B_1OL_1$  and  $POR$  have mutually perpendicular arms,  $\angle POR = \theta$ . Similarly  $\angle QOR = \theta$ .

If the reflected beams  $R_1$  and  $R_2$  interfere constructively, the difference in optical path must equal a whole number of wave lengths, viz.,  $n\lambda$ , where  $n$  is an integer.

Figure 284 represents a section of space lattice.  $L_1$  and  $L_2$  are two planes separated by a distance  $d = OR$ .  $B_1$  and  $B_2$  are two beams of x-rays incident at points  $O$  and  $R$  of planes  $L_1$  and  $L_2$ , respectively, at the glancing angle  $\theta$ .  $B_1$  and  $B_2$  are reflected as  $R_1$  and  $R_2$  at the same angle. Draw  $OP$  and  $OQ$  perpendicular to  $B_2R$  and  $RR_2$  at  $P$  and  $Q$  respectively. Since angles  $B_1OL_1$  and  $POR$  have mutually perpendicular arms,  $\angle POR = \theta$ . Similarly  $\angle QOR = \theta$ .

Figure 284 represents a section of space lattice.  $L_1$  and  $L_2$  are two planes separated by a distance  $d = OR$ .  $B_1$  and  $B_2$  are two beams of x-rays incident at points  $O$  and  $R$  of planes  $L_1$  and  $L_2$ , respectively, at the glancing angle  $\theta$ .  $B_1$  and  $B_2$  are reflected as  $R_1$  and  $R_2$  at the same angle. Draw  $OP$  and  $OQ$  perpendicular to  $B_2R$  and  $RR_2$  at  $P$  and  $Q$  respectively. Since angles  $B_1OL_1$  and  $POR$  have mutually perpendicular arms,  $\angle POR = \theta$ . Similarly  $\angle QOR = \theta$ .



Hence,

$$PR + RQ = n\lambda.$$

But

$$PR = RQ = d \sin \theta;$$

therefore,

$$n\lambda = 2d \sin \theta. \quad (2)$$

This equation is known as Bragg's law.

Reflection is taking place also at all parallel planes below these two. Path differences of  $\lambda$ ,  $2\lambda$ ,  $3\lambda$ , etc., are encountered, just as in the case of optical dif-

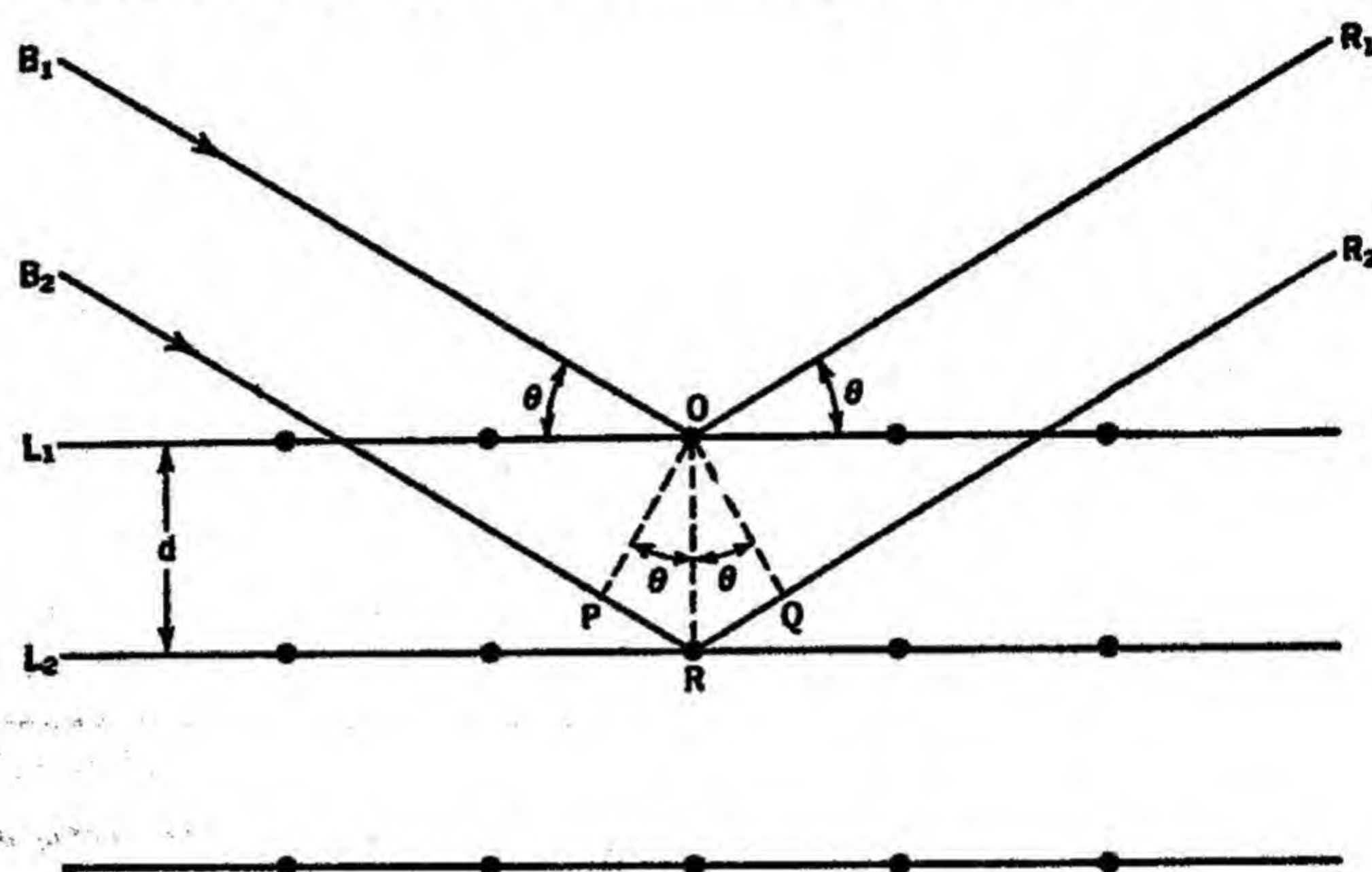


Fig. 284. Bragg's law. X-rays reflected at parallel planes in a crystal.

fraction, and  $n$  represents the order of the x-ray spectrum. Corresponding to each value of  $n$  is a bright maximum on a screen receiving the diffracted radiation.

Since there are many series of parallel planes in a crystal, rotation of the sample will give different values of  $\theta$  and a series of values for  $d$ . This series of  $d$  values is characteristic of the substance and serves to identify it. It should be noted that for constructive interference to take place,  $\theta$  can assume only certain values,  $\theta_n$ , which are called the *Bragg angles*.

## 5. THE WAVE LENGTH OF X-RAYS

In order to use Bragg's law for the purpose of determining the grating constant, we must have available a source of radiation of known wave length. We have seen in Chapter 22 that when electrons moving with great velocity impinge upon a solid substance, x-rays are emitted by the substance. Radiation of this nature covers a fairly wide region of the spectrum. This continuous spectrum is of value in ordinary x-ray work, such as that described in Chapter 22, but it cannot be used as a source of homogeneous radiation. It is found, however, that when the voltage exceeds a certain value, depending upon the target of the x-ray tube, a line spectrum is detectable, superimposed, as it were, on the continuous spectrum. If the intensity of the x-ray beam (as measured by ionization



current) is plotted against wave length as in Fig. 285, a continuous curve is obtained, corresponding to the continuous x-ray spectrum. At certain points, however, peaks occur corresponding to the line spectrum. The location of these peaks varies with the element; hence, the term *characteristic radiation* is applied. For every element a series of monochromatic x-radiations can be obtained.

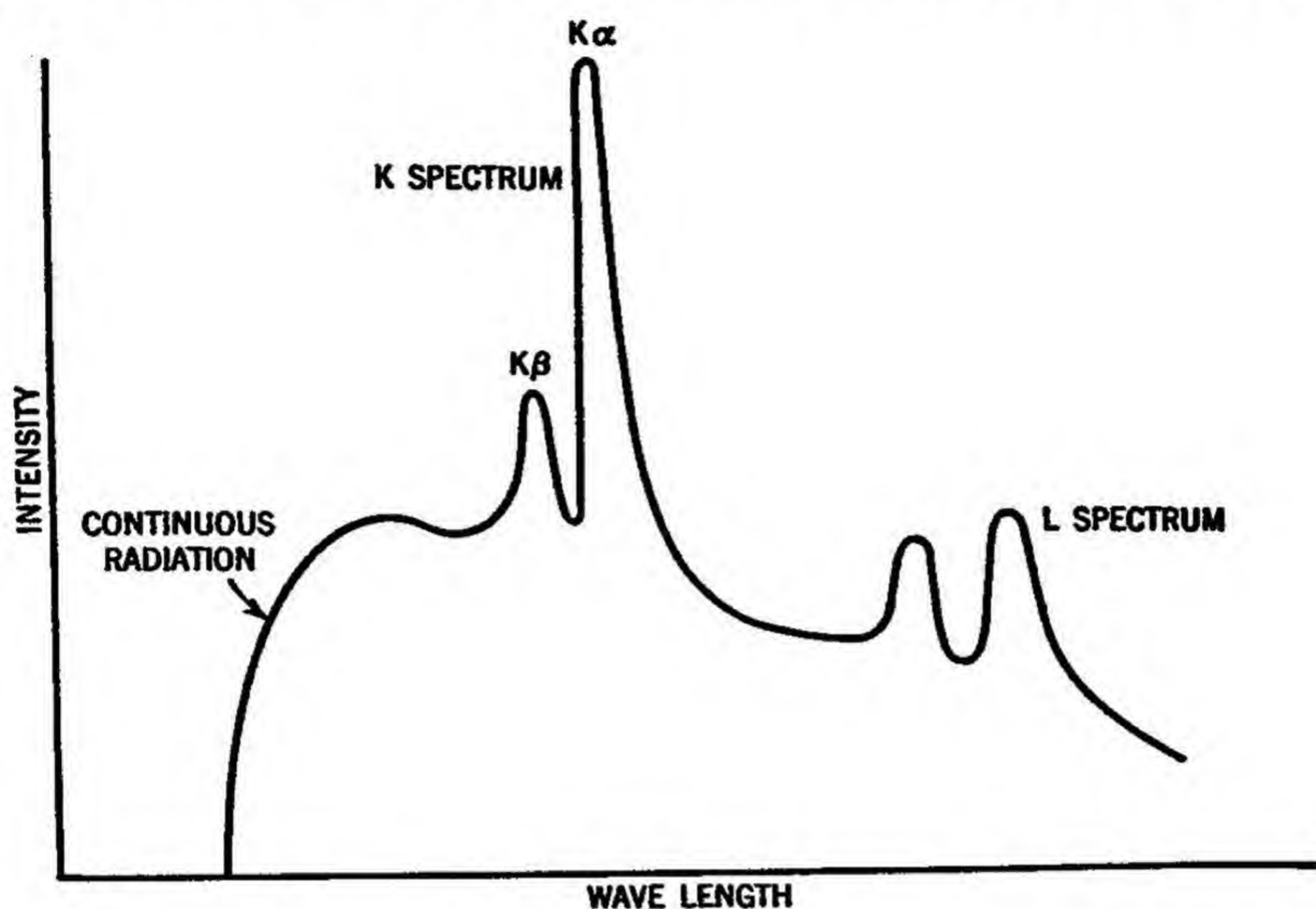


Fig. 285. Continuous radiation. The peaks correspond to characteristic lines.

Figure 286 represents a typical spectrum of the characteristic radiation of an element. Two series of lines are present: the *K* and *L* series. In each series

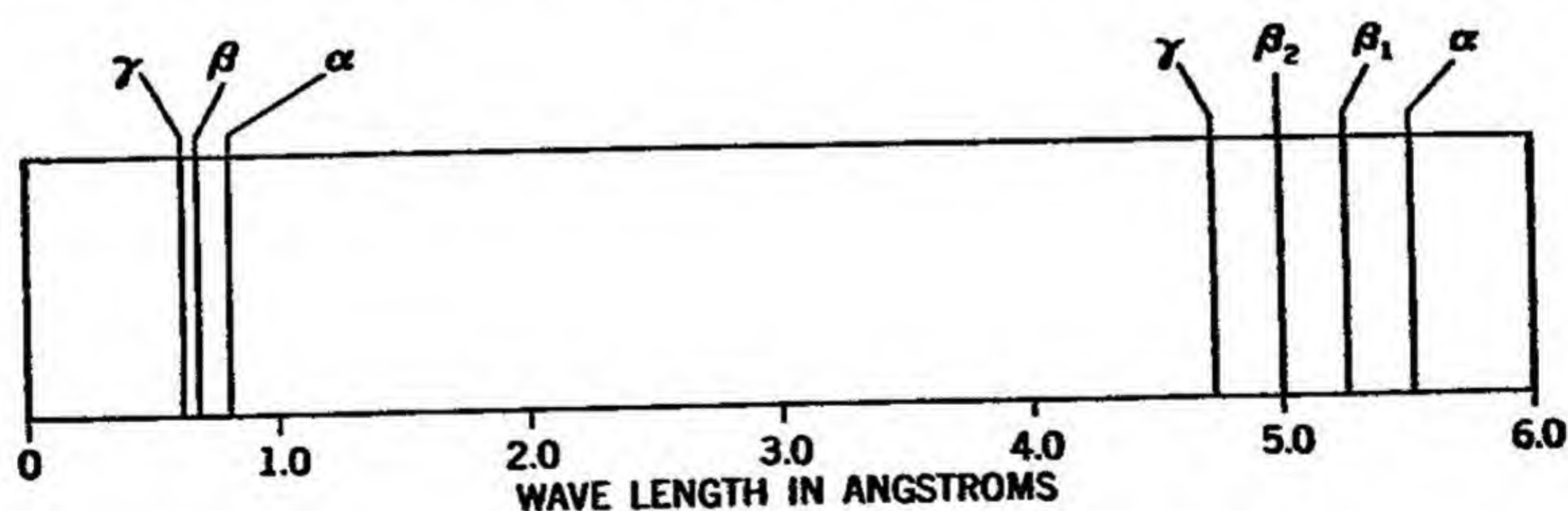


Fig. 286. The *K* and *L* spectra of an element.

are shown three lines:  $\alpha$ ,  $\beta$ , and  $\gamma$ . Thus, we refer to the  $K\alpha$  line or the  $L\beta$  line. Unlike optical spectra, the lines of the x-ray spectra of the various elements are similarly placed; i.e., the dispersion is not anomalous. Figure 287 shows the *K* x-ray spectra of a number of elements.

The wave length of the characteristic x-rays to be expected when a given element is used as a target can be determined from a relation first discovered by Moseley. Since x-rays are of the same nature as light the frequency  $\nu$  of x-radiation is given by

$$\nu = \frac{c}{\lambda}, \quad (3)$$



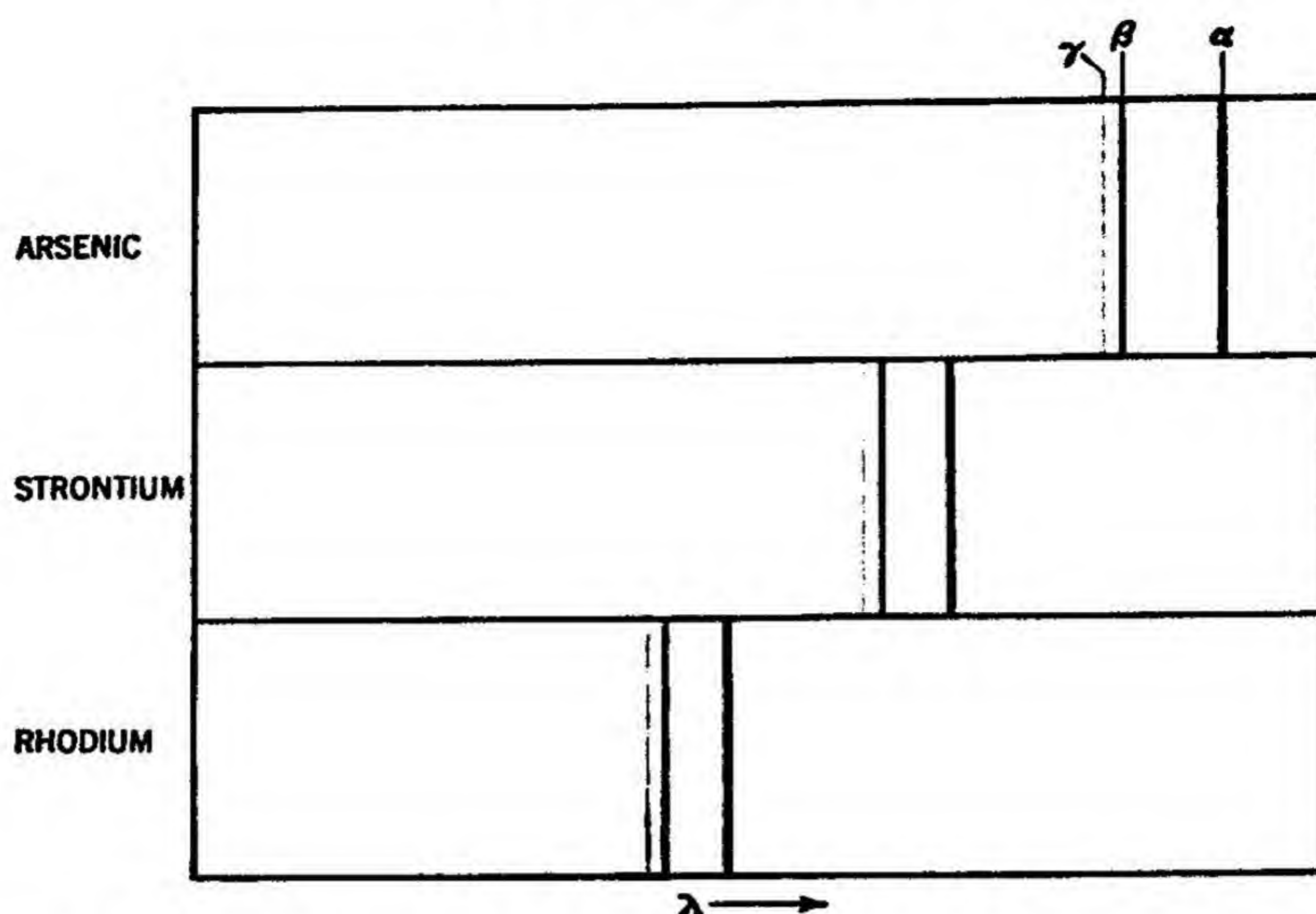


Fig. 287. The  $K$  spectra of three elements, illustrating the decrease in wave length of  $K$  lines with increasing atomic number.

where  $c = 3 \times 10^{10}$  centimeters per second, the speed of light. By plotting the square root of the frequency against the atomic number  $Z$  (the position of an element in the periodic table), Moseley obtained the following simple relation:

$$\sqrt{\nu} = a(Z - \sigma) \quad (4)$$

where  $a$  and  $\sigma$  are constants varying with the series ( $K$ ,  $L$ , . . .) under consideration.

Since characteristic radiation is a function of atomic number, we should expect it to be related to the distribution of the electrons in the orbital shells of the atom. In the discussion of optical spectra in Chapter 41 it was stated that these spectra are due to energy changes taking place in the atom. On the absorption of energy an electron is removed to a position of greater potential energy, farther from the nucleus. When an electron drops back to take the place of the displaced electron, energy is released in the form of radiation. The character of the radiation depends upon the location of electrons affected. Light radiations occur when an outer

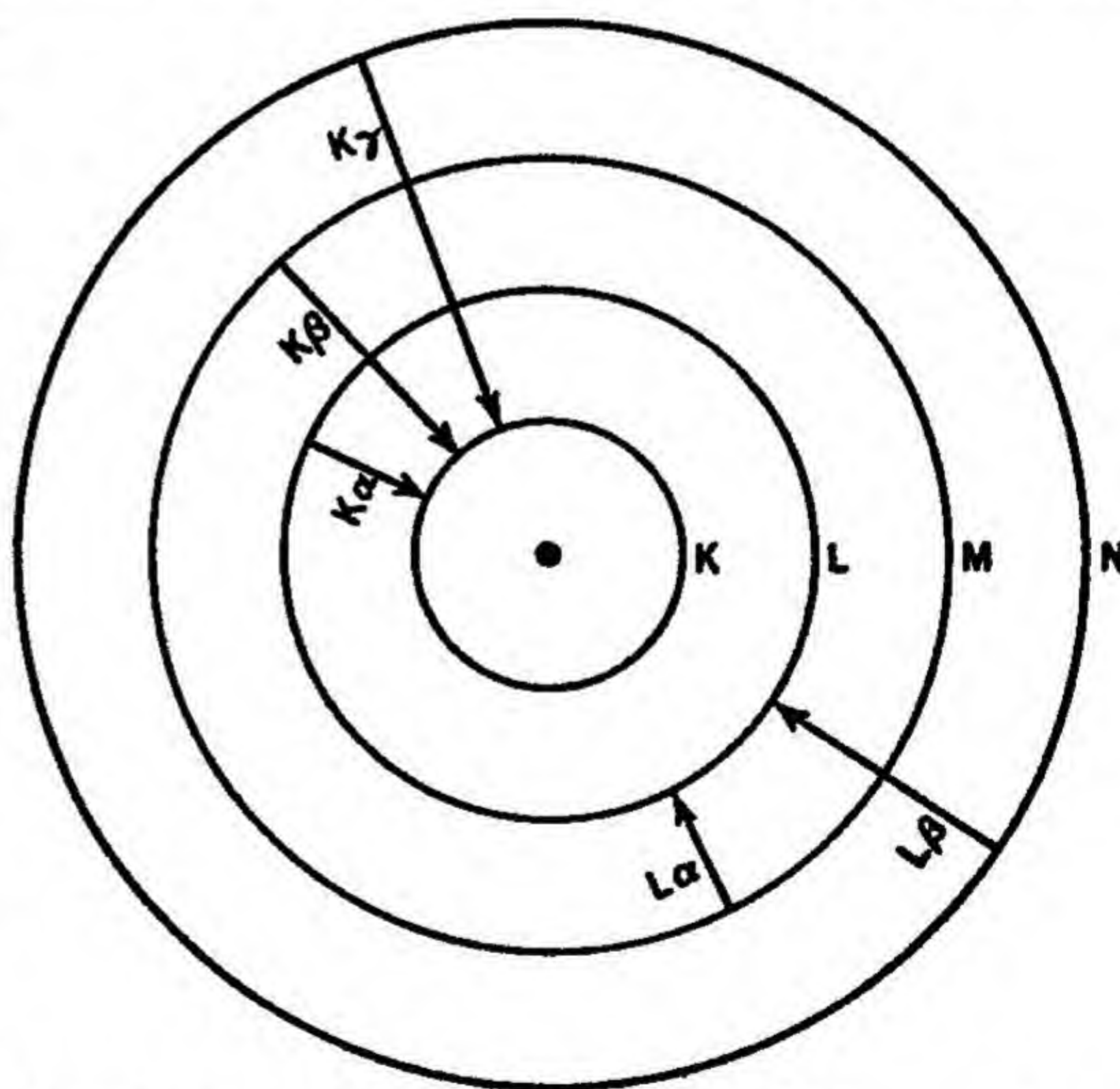


Fig. 288. Classical atomic model, showing  $K$ ,  $L$ ,  $M$ , and  $N$  orbits.

valency electron is moved into one of the "virtual" orbits and an electron falls into an orbit nearer the nucleus. When an inner electron, close to the nucleus, is knocked out of position, and an electron falls in its place, x-rays are emitted.



Figure 288 is a diagram of the model atom showing the inner orbits  $K$ ,  $L$ ,  $M$ , and  $N$ . The arrows between orbits indicate the electron "drops" which give rise to the correspondingly lettered peaks of the curve in Fig. 285. The order of relative frequency or probability with which these changes take place is  $\alpha$ ,  $\beta$ ,  $\gamma$ . Thus for the  $K$  spectra the probability of a transition decreases in the order  $L \rightarrow K$ ,  $M \rightarrow K$ ,  $N \rightarrow K$ .

## 6. EXCITATION OF X-RAY SPECTRA

By applying Einstein's photoelectric equation it is possible to determine the minimum energy which the bombarding electrons of the x-ray tube must possess in order to excite the various  $K$ ,  $L$ , and  $M$  spectra. Expressing the energy in terms of peak voltage  $V$  applied to the tube, the minimum wave length in Ångström units,  $\lambda_{min}$ , (wave length at which the white or continuous radiation cuts off) is given approximately by the Duane-Hunt relation:

$$\lambda_{min} = \frac{12,345}{V} \quad (5)$$

Since, from Moseley's law:

$$\lambda = \frac{c}{a^2(\zeta - \sigma)^2}, \quad (6)$$

we have in these two equations a means of determining the nature of the target required for radiation of a certain wave length and also the approximate voltage necessary to excite this radiation. In practice the excitation potential is determined by substituting in equation (5) the wave length of the  $K$  absorption edge which is given in Table 31. This table is a list of some of the elements which can be used as targets in an x-ray tube. The elements are listed in the order of atomic number opposite the wave lengths of the  $K\alpha$  doublet, the  $K\beta$  line, and the  $K$  edge.

TABLE 31

TARGET ELEMENT	ATOMIC NUMBER	WAVE LENGTH IN ÅNGSTRÖM UNITS			
		$K\alpha_2$	$K\alpha_1$	$K\beta$	$K$ Absorption Edge
Chromium	24	2.2889	2.2850	2.0806	2.0659
Iron	26	1.9360	1.9321	1.7530	1.7394
Cobalt	27	1.7892	1.7853	1.6174	1.6040
Nickel	28	1.6583	1.6545	1.4970	1.4839
Copper	29	1.5412	1.5374	1.3893	1.3774
Molybdenum	42	0.7128	0.7078	0.6310	0.6184

To achieve maximum contrast between the  $K$  lines and the background a peak potential of 3.5 to 4 times the excitation potential is applied to the tube.

The choice of target depends upon the nature of the material being examined. It is desirable in studying a substance to use a target consisting of an element of



lower atomic number. For example if the specimen to be analyzed is thought to have a high percentage of nickel, an iron target would be used. This choice is determined by the fact that the energy of the  $K$  orbit increases with atomic number. If an element of higher atomic number is selected, its radiation will possess sufficient energy to cause the atoms of the element of lower number to emit x-rays and thus fog the film.

The  $K\alpha$  rays are used for monochromatic radiation. In order to eliminate the  $K\beta$  lines an appropriate filter must be used. The choice of filter material is determined by the  $K$  edge which is the critical absorption wave length. If a beam of x-rays impinges on a plate composed of a certain element, it is found that the absorption of the rays as measured by the ionization current is not uniform. Absorption discontinuities occur for each of the  $K$ ,  $L$ ,  $M$ ,  $N$ , and  $O$  spectra. In Fig. 285 this discontinuity for the  $K$  spectrum is seen at the left of the figure. The critical wave length at which this discontinuity occurs is called the *absorption edge*. Wave lengths shorter than the critical value will be absorbed to a much greater degree than the longer wave lengths; hence a material of appropriate absorption edge can be used to filter out certain x-rays emanating from a different material. The  $K$  edge of an element is located just below the  $K\beta$  line. To obtain monochromatic radiation with a given target element, the filter-screen element is chosen so that its  $K$  edge lies between the  $K\alpha$  and  $K\beta$  line of the target. Thus for a molybdenum target ( $K\alpha = 0.710 \text{ \AA}$  and  $K\beta = 0.631 \text{ \AA}$ ) zirconium would be a suitable choice for a filtering screen, since its  $K$  edge has a value of  $0.687 \text{ \AA}$ .

## 7. X-RAY DIFFRACTION METHODS

The essential parts of any x-ray diffraction apparatus are a system of pin-holes or collimating slits to limit the x-ray beam, an arrangement for holding and manipulating the sample, and a means of recording the scattered radiation. Two methods are of outstanding importance — the powder method which uses a polycrystalline specimen, and the single crystal method in which rotation, oscillation, or moving-film techniques are employed. Although the powder method is at present the most popular, single crystal techniques provide a more powerful tool for analysis of complex organic molecules as an effective means of determining grain size, orientation, recrystallization, and distortion. Single crystal diagrams, however, are quite difficult to interpret. Reciprocal lattice principles are of great assistance in reducing this difficulty of interpretation. For the criminalistician the powder method is more suitable for the analysis of small quantities of clue materials.

As we have seen, there are a number of sets of parallel planes in an atom. If a collimated beam of monochromatic x-rays is permitted to strike a crystal, the manner in which the radiation is reflected will depend upon the orientation of the crystal. Such a crystal may not lie in the correct position for reflection; it is then necessary to rotate it in order to obtain all the possible angles of reflection. If, however, a powdered sample is presented to the x-ray beam, the randomness



of orientation of the many crystals will result in some of the crystals lying at each of the possible angles of reflection so that every set of planes in the crystal will contribute to the diffraction picture. The result will be a complete series of  $d$  values and an adequate description of the crystal.

Figure 289 is a schematic diagram of the Debye-Scherrer camera. The camera is in the form of a cylinder. A beam of monochromatic x-rays enters the

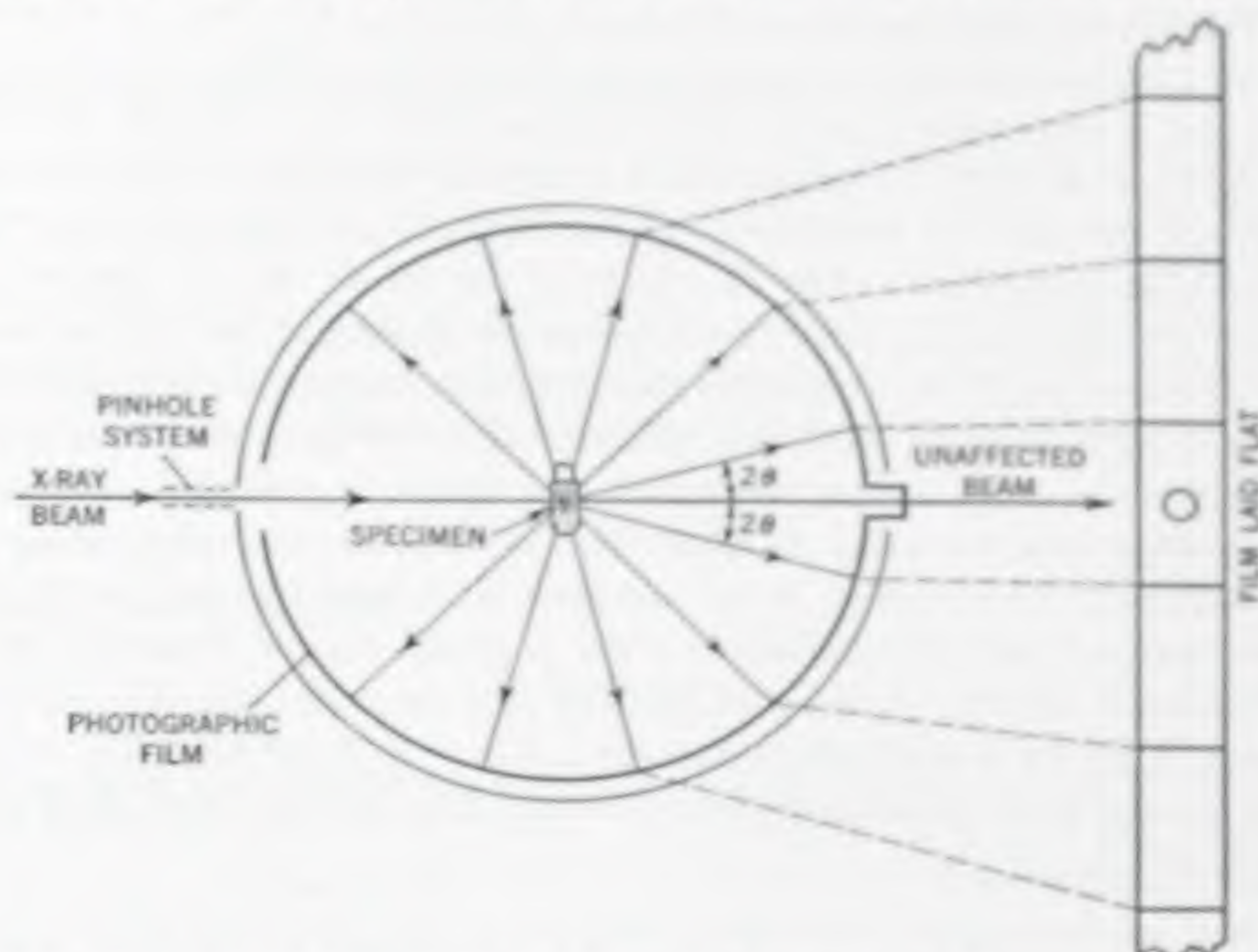


Fig. 289. Cylindrical powder diffraction camera (schematic diagram).

cylinder through a pinhole or slit which serves a collimator. The beam then strikes the powdered specimen at the center of the camera. The unaffected x-rays pass through the camera and emerge through a hole. The diffracted rays are reflected in many directions against the wall of the cylinder, in which there is placed a lining of film to receive the reflected x-rays and record the pattern.

In preparing the sample the powder is screened through a sieve. A 200 mesh is used for metals or alloys; a 350 mesh is used for minerals or artificial materials which have coarse crystals. The specimen may be mounted in several ways. Amorphous materials such as glass, collodion, or glue are employed in mounting so that there will be no additional crystal pattern. The specimen may be mounted in a thin tube or rolled into a fine wire by means of glue or collodion.

## 8. ANALYZING THE PATTERN

The film pattern formed by the diffracted x-rays depends upon the type of collimating entrance used. If a slit is used, the lines on the film are straight. With the pinhole collimator the x-rays are reflected from the crystals as the generatrices of coaxial cones. Figure 291 shows the intersection of these cones with the flat sheet and the resulting rings. The intersection of the cones with a





Fig. 290. X-ray diffraction camera. (Courtesy, North American Philips Company, Inc.)

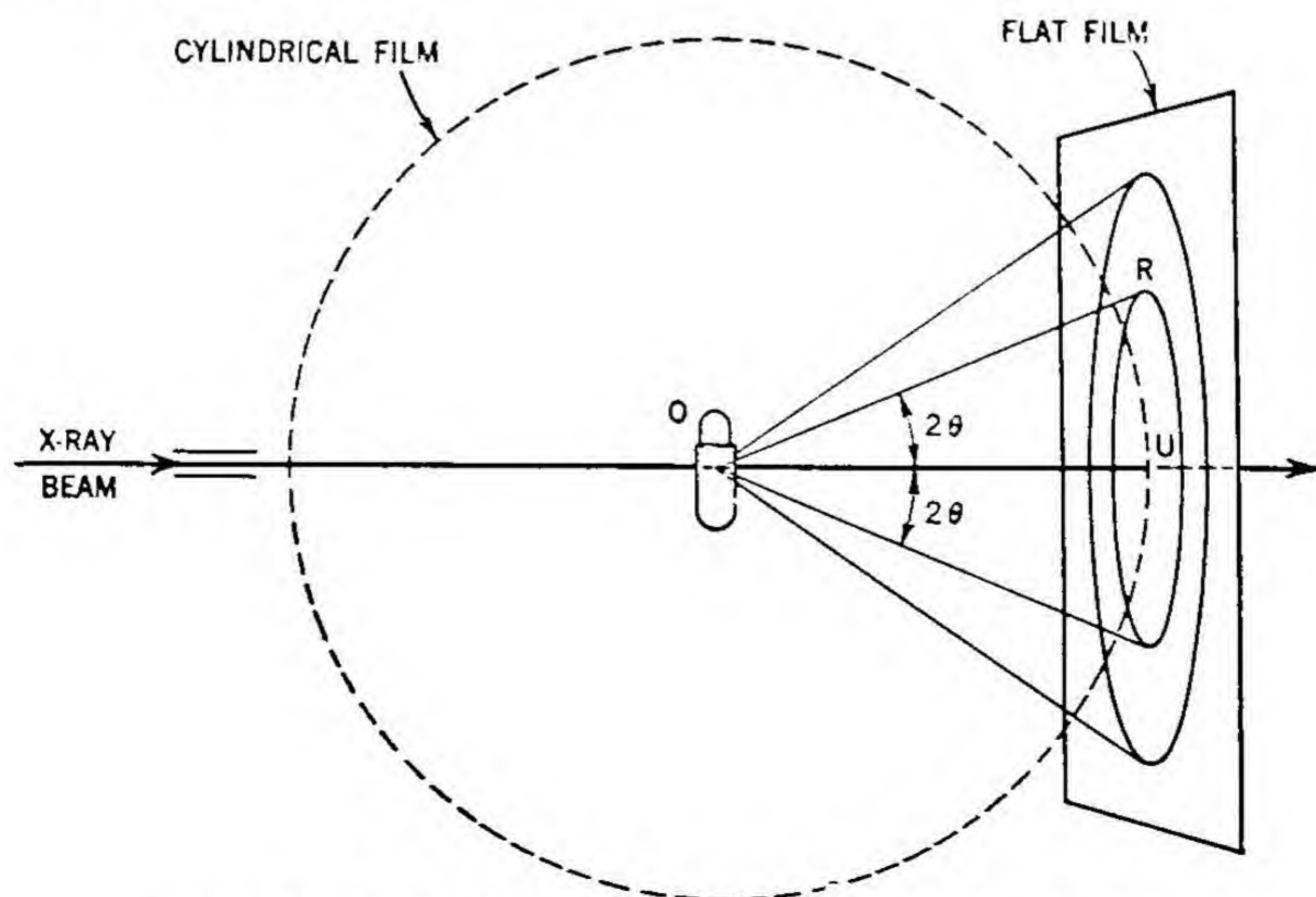


Fig. 291. Reflection of x-rays in powder method.



cylindrical film will result in a set of more complicated curves which, however, appear on the film to be arcs of concentric circles.

The angle  $\theta$  can be calculated from the simple geometrical relationships which are illustrated in Fig. 291. The angle of the cone is seen to be  $4\theta$  in the diagram. The reason for this value can be seen from Fig. 292 which shows the formation of one-half of the cone, viz.,  $ROU$ .

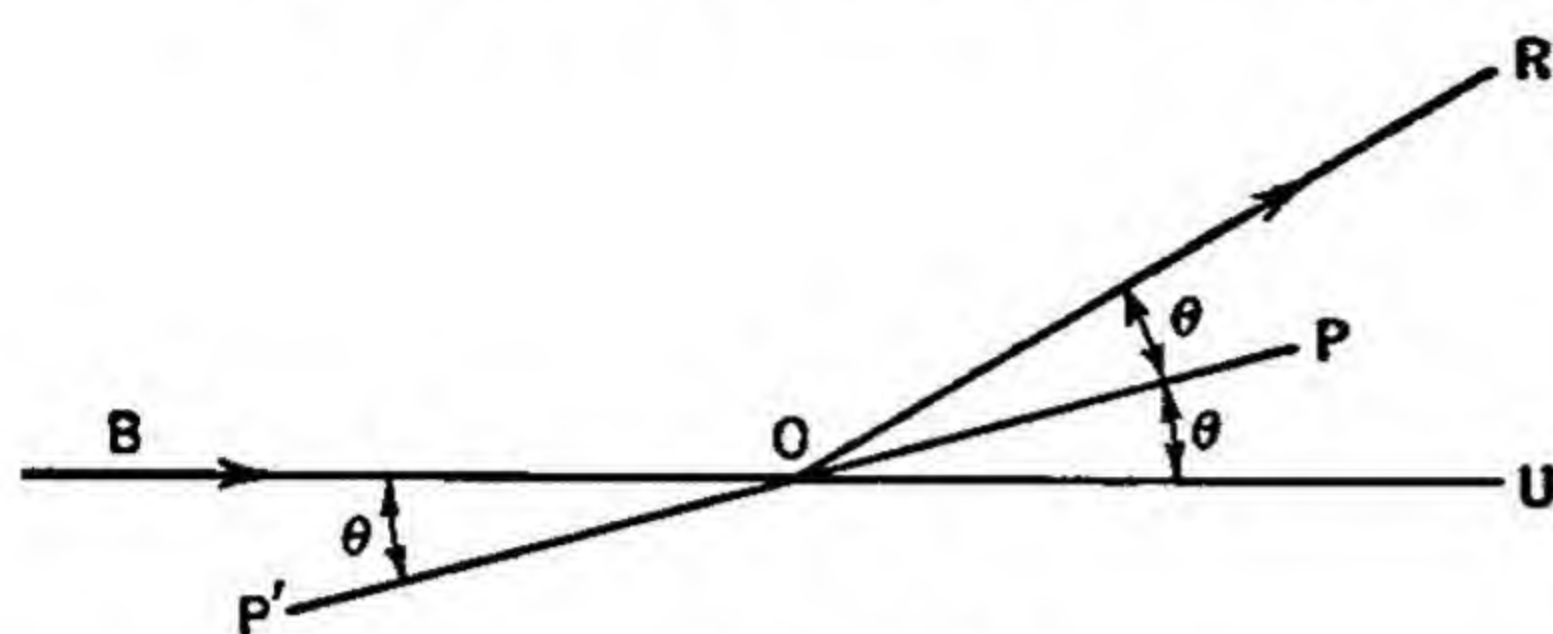


Fig. 292.

$PP'$  is a lattice plane. The x-ray beam strikes the plane at  $O$  at an angle  $\theta$  and is reflected in the direction  $R$  at the same angle. Since  $\angle POU = \angle BOP' = \theta$ ,  $\angle ROU = 2\theta$ . Hence the whole angle of the cone is  $4\theta$ .

If the linear distance subtended at the film is  $S$  and the radius of the camera is  $r$ , we have:

$$\theta = \frac{S}{4r}. \quad (7)$$

The values of  $\theta$  are calculated for each line on the strip of film. These values are substituted in equation (2) and a series of  $d$  values obtained. From the  $d$  values the crystals can be identified by reference to a set of tables such as the Hanawalt Tables.<sup>1, 2</sup> The type of crystal can also be determined by calculating the Miller indices and the lattice parameter. Tables of grating constants are available in the *International Critical Tables* and the *Handbook of Chemistry and Physics*.

Instead of identifying a substance by calculating  $d$  values, a simpler procedure may be employed if a sufficient number of standard reference films is available. The film bearing the unknown pattern is matched with the standard film of a known element or compound. If the lines in the standard film are matched in location and intensity by those of the unknown, the known standard substance is present in the unknown. If all the lines in the unknown are not thus accounted for, another substance is present and comparison with additional standard films is necessary.

If two samples of clue material are submitted to the laboratory for comparison — for example, powder found on the garment of a suspect and powder from an area at the scene of a burglary — both specimens may be studied for our purposes by comparison of the two films. If the diffraction patterns correspond, the compounds present are the same, and a supplementary spectrographic analysis should be made. If they are radically different, no further analysis is necessary.

## 9. APPLICATIONS

The possibilities of x-ray diffraction in chemical analysis have already been broadly outlined. The two problems of criminalistics — namely, identification and comparison — lend themselves readily to solution by this method. Com-



parison is accomplished by matching the lines on the film of the known and unknown.

In the identification of a crystalline compound, x-ray diffraction possesses certain advantages over chemical analysis: Analysis by x-rays requires only a small amount of sample; the necessity for separating and preparing the material is eliminated, with an immense saving in time, a factor which can be of decisive importance in a case; finally, the photographic film offers a permanent, objective record which can, if necessary, be submitted in court to substantiate testimony. In relation to spectrographic analysis (optical spectrography), x-ray diffraction possesses the following advantages: x-ray spectra depend only on the atoms and not on the molecules present and hence complications such as band spectra and other effects due to chemical combination are avoided; the number and relative intensity of lines in x-ray spectra are not dependent on excitation conditions; moreover, the line pattern is much simpler than that of the optical spectrogram. The picture of the crystalline structure which is provided by x-ray diffraction is a decided advantage in distinguishing between mixtures and compounds, and in distinguishing various phases of the same substance, e.g., polymorphs such as wurtzite and sphalerite.

The following are some of the specific applications to police work:

(a) *Metallurgy* — In addition to the usual comparison problems of metals presented to the Laboratory, cases of sabotage sometimes arise. A metal part such as a clamp or tongs may break under normal tension. The question is asked: "Was this break due to defective materials or to criminal tampering?" Ordinarily petrographic methods are employed. Sometimes, however, these methods fail because the crystals are opaque or not large enough to be resolved by the microscope. Another example of the use of x-ray diffraction would be in the identification of deposits on gas cylinders, tanks, and feed lines. In an act of sabotage a hole may be formed in such a container by means of an acid. The area surrounding the hole is covered with scales of unknown origin. Are the holes due to natural corrosion or to the application of an acid?<sup>3</sup>

X-ray diffraction is applicable to metals in the following ways:

- i. To distinguish among the various phases of the fifteen or more polymorphic metals. Different heat treatments produce different crystal forms. For example, iron carbide when cooled rapidly will show a diffraction pattern different from that of a slowly cooled specimen.
- ii. Identifying alloys formed by mixtures such as copper-tin (bronze), copper-zinc (brass), copper-silver, etc. Some of these alloys form complex intermediate phases.<sup>4, 5</sup>
- iii. Detecting distortion of grains due to tension or strains.
- iv. Detection of fragmentation of grains due to exceeding the elastic limit.
- v. Detection of undesirable "preferred orientation" in a metal due to directional cold work.<sup>6</sup>
- vi. Determination of the effect of improper annealing.<sup>7</sup>
- vii. Determination of surface stresses on welded joints while under load.<sup>8</sup>



viii. Detecting the causes of metal failures in general.

These types of examination are of value in the investigation of sabotage and accidents and in the comparison of two pieces of metal.

(b) *Paint* — The examination of paints, particularly of automobiles involved in accidents, is a common laboratory problem. This is usually accomplished with the spectrograph. Many pigments, however, contain titanium dioxide which may exist in forms differing only in the atomic lattice. These forms are known as *rutile* and *anatase*. X-ray diffraction is the only method of distinguishing them.

(c) *Precious Gems* — The identification of pearls and precious stones as genuine presents a serious problem to the police scientist. Ordinary x-ray methods and ultraviolet examinations are unsatisfactory. Examination by an expert jeweler is helpful. The most satisfactory objective method, however, is that of x-ray diffraction. This method is at a great advantage here because gems can be examined without alteration.<sup>9</sup>

(d) *Ceramics, Clays, and Soil Materials* — Soil materials from the scene of the crime are sometimes carried on the shoes of the criminal. X-ray diffraction methods offer an additional means of comparison of two samples. Comparison of fragments of broken earthenware can also be accomplished by this means. The analysis of many cement compounds is possible only by x-ray diffraction.<sup>10, 11, 12</sup>

(e) *Textiles* — Additional information concerning cloth and other fibrous material can be obtained by studying the orientation in the crystals of the fibers through x-ray diffraction methods. The identification of cotton, wool, and rayon fibers is accomplished in a more scientifically reliable manner.<sup>13, 14</sup>

(f) *Dust and Fine Powder* — One of the classical methods of associating a suspect with the scene of the crime is by means of fine particles of matter found

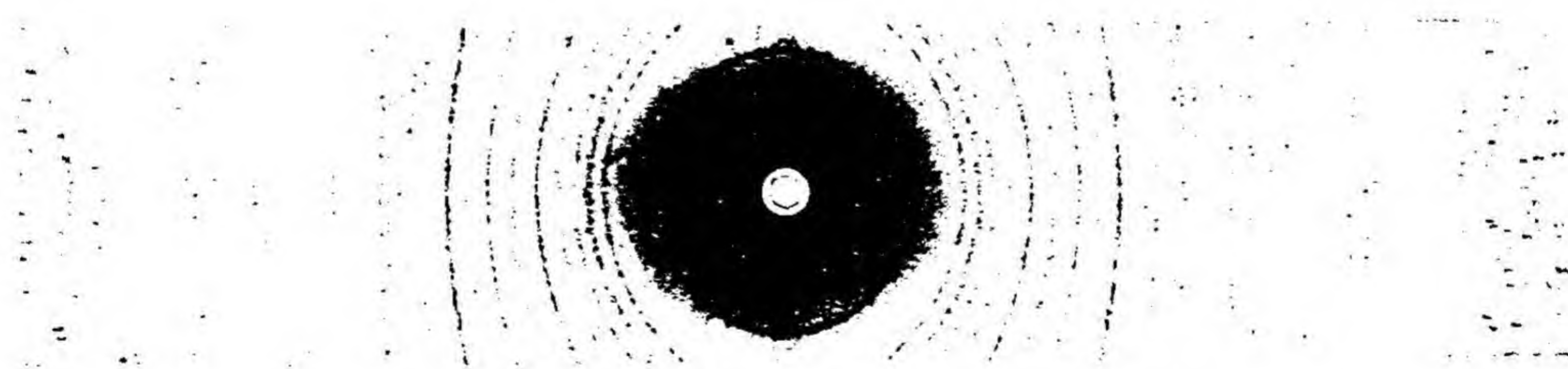


Fig. 293. X-ray diffraction pattern of quartz.

on his clothing or body. Edmond Locard was the first to give an extensive treatment of the microscopical examination of such clue material. O'Neill has given a more scientific approach to the subject, and stresses the difficulties involved in a microscopical analysis. Spectrographic analysis may be undesirable because of the consequent destruction of the minute trace. X-ray diffraction provides a valuable means of supplementary analysis. Factory dust, mine dust, quartz, and other powders have been analyzed in this manner. It is worth noting that the petrographic microscope cannot distinguish between free quartz and some silicate minerals.<sup>15, 16</sup>



(g) *Glass* — Although not a crystalline substance, glass is by no means truly amorphous. A diffraction film of glass will usually present a pattern of holes. It is possible by this method to compare samples of glass found in conjunction with a motor vehicle homicide or a burglary.<sup>17</sup> The method is, however, not as effective as a spectrographic analysis together with a comparison of the physical properties of the two samples.

(h) *Rubber* — Natural rubber can be distinguished from the synthetic rubbers. Moreover, distinctions can be made among the synthetic products. The crystal pattern in rubber is produced by stretching the sample.

(i) *Narcotics*<sup>18</sup> — In cases involving violations of laws relating to the use or sale of narcotics, it is necessary to prove that the evidence submitted actually contains a narcotic. Usually the sample which is seized in evidence is in the form of a white powder. The white powder may contain a high percentage of some substitute such as milksugar. Adulterations of this nature can make chemical detection of morphine, cocaine and other narcotics quite difficult. By x-ray diffraction, however, it is possible to make a direct analysis of the crystal structure and to determine the nature of a narcotic often in less than the time required by chemical analysis. Moreover, this technique will differentiate between narcotics which are quite similar in chemical reactions. For purposes of comparison a file of powder films of narcotics should be maintained at the laboratory. Barbiturates, which have but recently come under the cognizance of the law, offer special difficulties of analysis. Frequently, in distinguishing between barbiturates, the analyst must rely on mixed melting point determinations. Where impurities are present, additional difficulties are encountered. Such an analysis can be greatly simplified by means of x-ray diffraction films such as those shown in Fig. 294.

(j) *Gunpowder* — Research in the identification of crystalline materials used in explosives by means of x-ray diffraction has recently been undertaken.<sup>19</sup> The identification of powder in this manner can be quite helpful in a criminal case. For example, the source of the powder which was used in the construction of a package bomb may be traced if the nature of the explosive can be determined.

(k) *Poisonous Mixtures* — When a poison is mixed with other substances in order to disguise its nature, difficulties can arise in making a correct analysis. For example, in a recent case a cyanide had been mixed in a box of salted nuts. Chemical analysis could not determine whether the poison was sodium cyanide or potassium cyanide. The presence of sodium chloride interfered with what would otherwise have been a simple analysis. A crystallographic examination, of course, would have been of great assistance here. The rapid and relatively simple method of x-ray diffraction, however, readily resolved the difficulty.

## 10. LIMITATIONS OF THE METHOD

X-ray diffraction, as we have seen, has many features which recommend its use in the field of criminalistics: economy and simplicity of method, permanency of the record, preservation of the evidence even in minute traces, and informa-



tion concerning the state of chemical combination of the substances present. There are, however, several disadvantages which are of considerable importance but which in the main affect the quantitative rather than the qualitative value of the method.

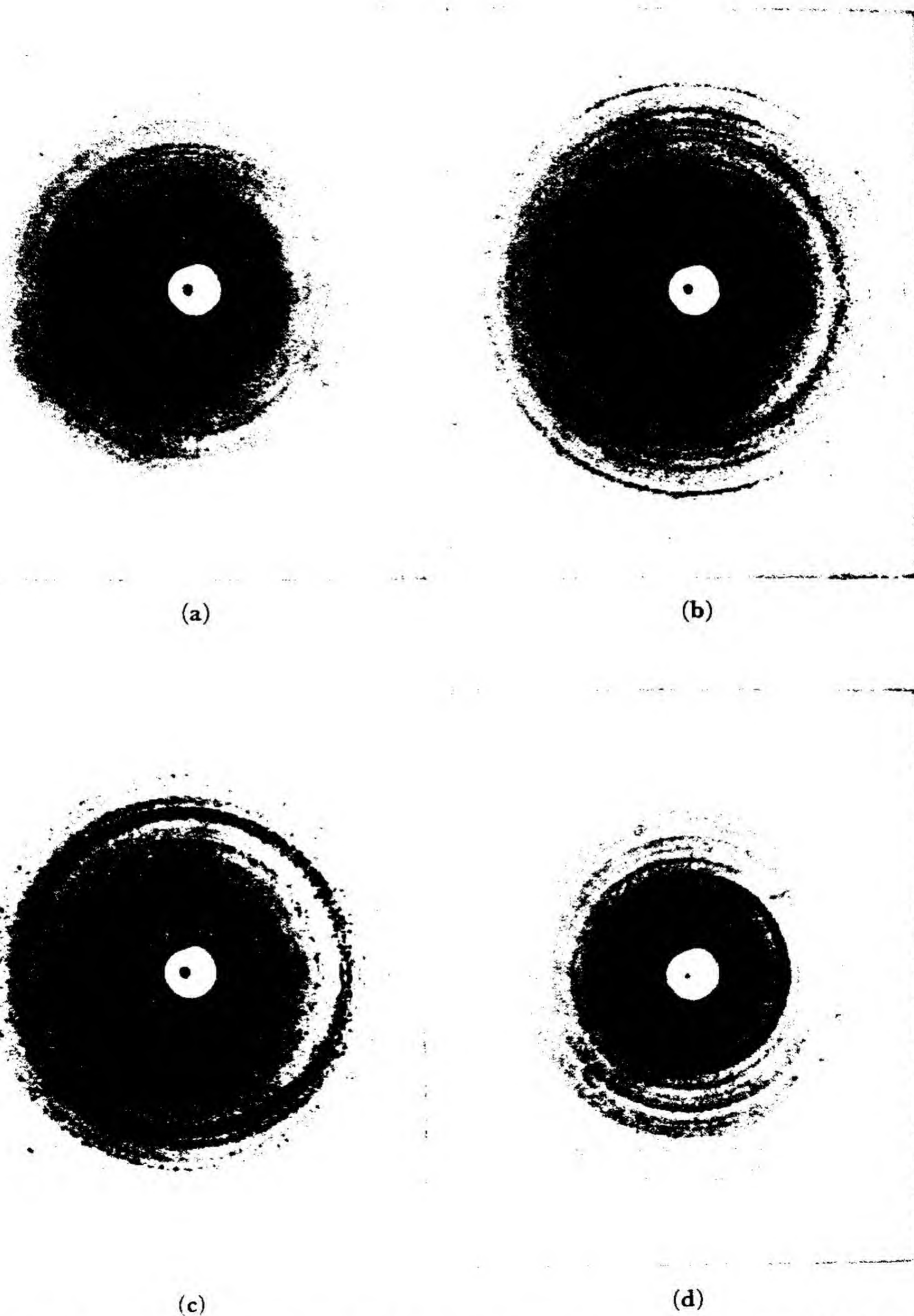


Fig. 294. X-ray diffraction pattern of barbiturate compounds: (a) cyclobarbital; (b) sodium pentobarbital; (c) phenobarbital; (d) sodium amytal. (Filtered copper radiation)



1. The information derived from the x-ray pattern is not comprehensive; that is to say, the lines on the film tell us what substances are present, but cannot inform us conclusively what substances are *not* present.

2. The method is most effective with solid crystalline substances. Approximately 5 per cent of solid inorganic substances are amorphous and will not yield a sharp diffraction pattern. The diffuse halos which are obtained in the latter, however, are valuable for comparison work.

3. Many substances will give a very weak pattern. If these are in the presence of substances of stronger pattern, they may be difficult to detect. Depending upon the substances involved it is possible that a substance may not be detected even though it represents 10 per cent of the mixture.

Fortunately, the information obtained through x-ray diffraction is eked out by spectroscopy and other techniques. The great value of the spectrograph lies in its ability to reveal minute traces of all the elements present. Thus, the two methods supplement one another and together form a powerful weapon for analysis.

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# CHAPTER 43

## COLOR ANALYSIS AND THE SPECTROPHOTOMETER

The fundamental problem of the police laboratory is that of identifying an object which is held in evidence as having come from the same source as another object which is associated with a suspect. For example: Did the hair found at the scene come from the suspect's head? Were the fibers found at the scene part of the clothing of this suspect? Did the paint flakes found at the scene of the accident fall from the suspect's car? In all of these questions the implied problem is one of comparison between two similar substances. The comparison is usually made by a chemical analysis. Frequently, however, the nature or available quantity of the substance is such that identification must be established by means of physical properties. Hair and glass are examples of such evidence. Two of the most important physical properties have already been discussed, namely, specific gravity and refractive index. The present chapter is devoted to a study of color, another very important physical property from the point of view of the police scientist. Some of the many applications of color to forensic science are the following: comparison of paints, cloth, dyes, inks, and papers by means of color; identification and tracing of sources of various materials by color analysis. These applications will be discussed in greater detail at the end of this chapter.

### 1. COLOR

The subject of color was for a long time one of the less well-organized branches of physics. This condition was the result of the conflicting interests of the contributors to the subject — psychologists, physiologists, artists, and physicists. Each profession had its own definitions and laws of color. Systems of classifying colors by means of their psychological attributes have long been in use. The Munsell<sup>1,2</sup> and Ostwald<sup>3,4</sup> systems are the most popular. The three attributes or parameters used in the Munsell system are *value*, *hue*, and *chroma*. By *value* is meant the relative brightness of a color in comparison with the gray scale, where black has a value of zero and white a value of ten. One of the nine intermediate values is assigned to a given color. *Hue* corresponds to the concept



by which a color is described as being red, yellow, green, or blue. In the Munsell notation hues are designated by ten symbols,  $R$ ,  $YR$ ,  $Y$ ,  $GY$ , etc. Colors having the same value and hue differ in the degree of their difference from gray. This quality is called *chroma*, which corresponds to saturation. By means of these three attributes a system of classification of colors was achieved. The system, however, is subjective, and is not the best suited to legal purposes.

There exist physical attributes of color which resemble these psychological parameters. They are called *dominant wave length* (corresponding to hue), *colorimetric purity* (chroma), and *brightness* (value). These physical parameters will be defined later. They will not, however, be used as a definition of color. The color of a substance will be defined, for our purpose, by the operations described below. These operations determine certain physical properties, a knowledge of which enables us to reproduce any color.

## 2. COLOR PROBLEMS IN THE LABORATORY

In relation to color the two chief problems of the police laboratory are: (a) The matching of colors — is the color of sample  $A$  the same as the color of sample  $B$ ? (b) The classification of colors, that is, a ready means of cataloguing the colors, say, of ink, paint, or paper so that on the arrival of a new sample in evidence at the laboratory the search for a color match is greatly restricted and the problem of locating the likely source is simplified. The solution of both of these problems lies in a method of adequately specifying color.

A sound method of color specification must depend upon objective physical measurements of optical properties. A procedure of matching colors from a collection of samples of various colored materials is unsatisfactory because of the inconstancy of the color of the sample with time. Moreover, color sense varies with the individual and is influenced by other factors, such as the field surrounding the sample and the manner of observation. The color match will vary, too, with the quality of the light by which the comparison is made and the angle at which the samples are viewed with respect to the sample and the illuminant. A method of objectively matching and specifying colors has been achieved by the use of the spectrophotometer.

## 3. SPECTROPHOTOMETRIC ANALYSIS

The spectrophotometer is an instrument designed to measure the intensity of the light transmitted or reflected by a substance at various wave lengths. Light from a standard source is divided into two beams. The beams are dispersed into spectra from which narrow wave length regions can be isolated. One of the beams is transmitted or reflected by the sample. A photoelectric cell or a photographic plate is used to record the transmitted or reflected beam and the direct beam. In this way a wave length by wave length comparison is accomplished.

The ordinary sample of material with which the police scientist deals reflects light of all wave lengths. If the relative quantity of light reflected by the



sample in the various wave length regions can be determined, the color of the material is adequately defined for purposes of comparison. If the reflectance values are plotted against wave length, the result is a spectral reflectance curve such as Fig. 295. In Fig. 296 we have the spectral reflectance curve of a green paint. For another sample of green paint to be considered identical with this paint, the reflectance curve of the second paint must be identical, over the wave length region studied, with that of the first paint. Thus the favorable comparison of a known sample with an unknown sample depends upon their having the same reflectance curves. The values

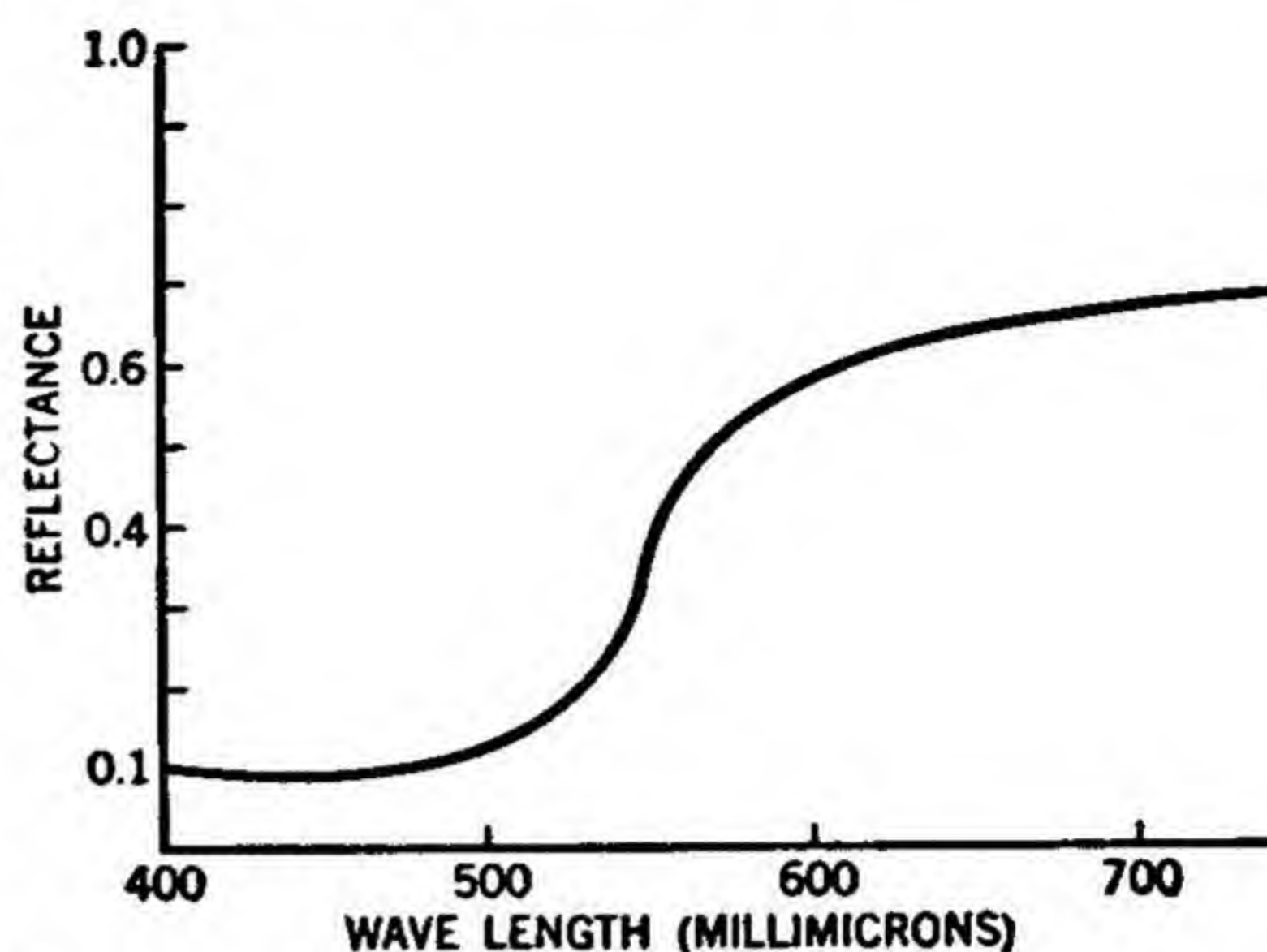


Fig. 295. Reflectance curve of an orange colored surface.

used in plotting the curves of Figs. 295 and 296 are obtained by means of a spectrophotometer. The reflectance factor is determined with this instrument for a number of wave length regions. These values represent an objective

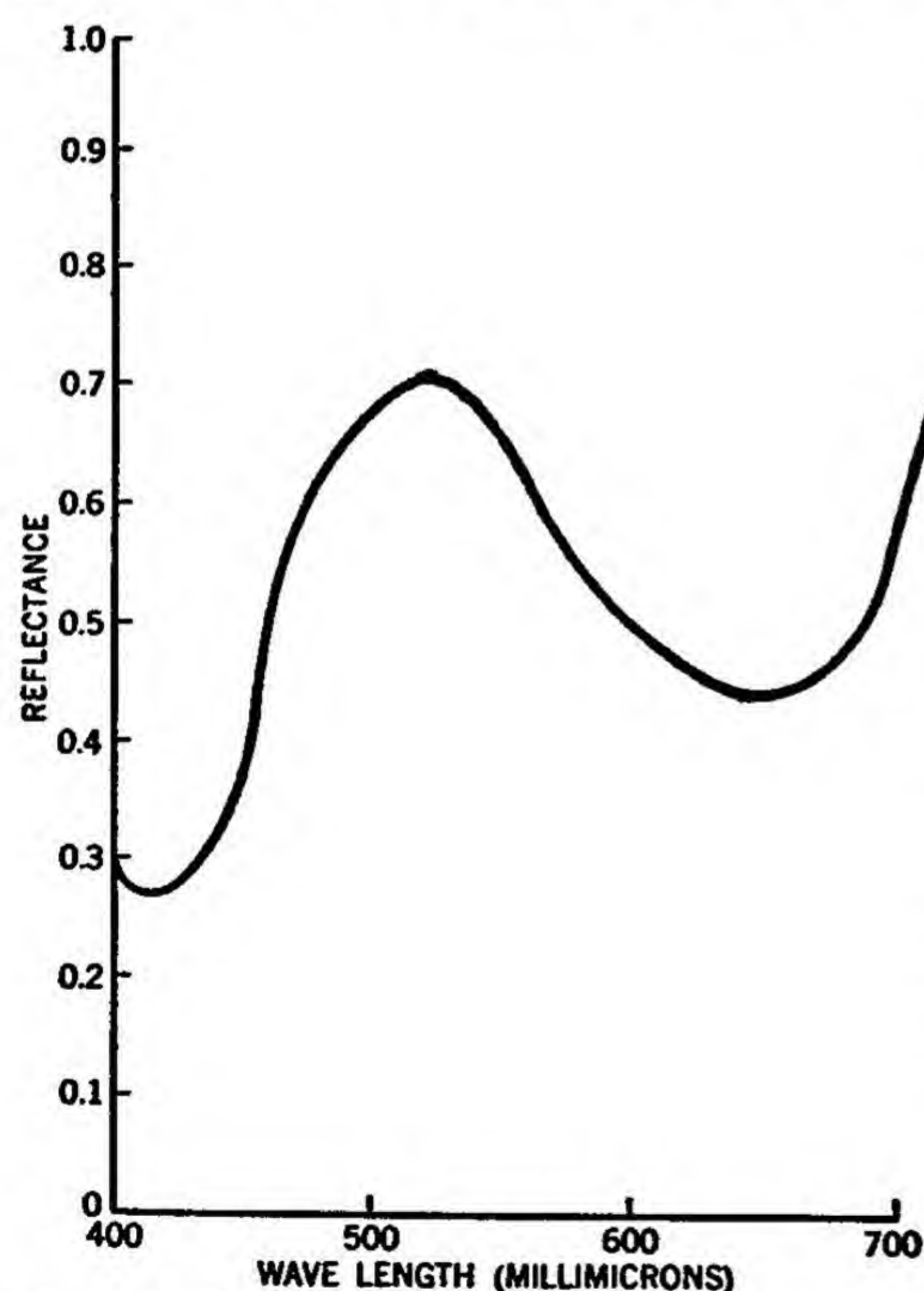


Fig. 296. Reflectance curve of a green paint.

specification of the color of the material and can be used as a court exhibit to establish the identity or difference of two colored samples. The spectral reflectance curve can be used to represent any color. A white surface which is a perfect reflector would be represented by the horizontal line corresponding to the ordinate unity. A perfectly black surface would be represented by the axis of the abscissas.

Spectrophotometric analysis, in addition to permitting comparison of the color of two samples, may also be used to specify objectively the color of a single sample. The former situation might occur when the paper of an anonymous letter is to be compared with the stationery of the suspected author; the latter situation would be had in a hit-and-run case where some paint is chipped off the car during

the accident. The investigator would be able, by means of methods to be described later, to classify the color of the paint on the car involved. From the paint classification data of automobile manufacturers, the make of car on which this type of paint was used could be determined.



#### 4. STANDARD ILLUMINANTS

Since the quality of the light transmitted or absorbed by a substance varies with the illuminant, it is important that a standard illuminant be used. An

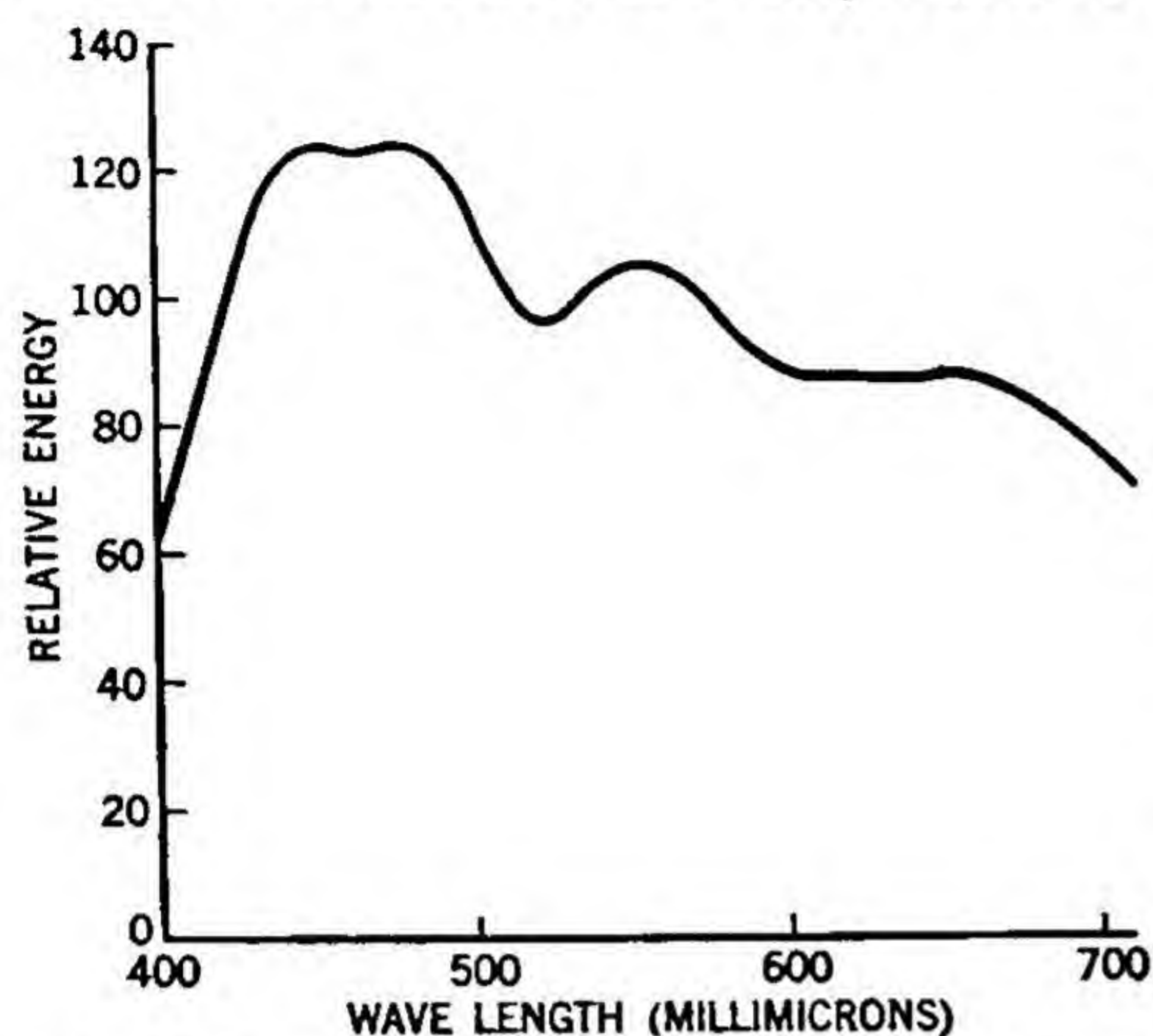


Fig. 297. Spectral energy distribution of *I. C. I. Illuminant C*.

international standard of illumination was adopted in 1931 at the meeting of the International Commission on Illumination.<sup>5</sup> This standard source of illumination is called the *I. C. I. Illuminant C*. (The abbreviation *C. I. E.* is sometimes used, from the French "Commission Internationale de l'Eclairage.") In its spectral distribution of energy, *Illuminant C* approximates average daylight.<sup>6</sup> The graph in Fig. 297 represents the relative distribution of energy radiated per unit time by *I. C. I. Illuminant C*. If the energy value given in this curve

at each wave length is multiplied by the reflectance of a material, such as that represented by Fig. 296, at the corresponding wave length; the resulting product gives the spectral energy distribution in the light reflected by the material.

It should be noted that other standard illuminants, such as *I. C. I. Illuminants A* and *B*, are also used. *Illuminant C* is average daylight; *Illuminant A* incandescent light; and *Illuminant B* is noon sunlight. The choice of illuminant is governed by the color of the sample. In specifying color the nature of the illuminant must be stated. In the present discussion it will be assumed that *Illuminant C* is being used throughout.

#### 5. EQUIVALENT STIMULI

The subject of color classification is closely connected with methods of synthesizing color stimuli. It is a well-known fact that the sensation produced by a given color stimulus can be matched by a combination of controlled amounts of three arbitrarily selected primaries.<sup>7</sup> These primaries may extend over a spectral region, e.g., red, blue, and green; or may be monochromatic, e.g., 460, 530, and 640 millimicrons respectively. (A *millimicron* is  $10^{-7}$  centimeters. This unit will be used here instead of the Ångström because it is used in the construction of the *I. C. I.* tables. The abbreviation is *mμ*.)

An instrument designed to match color sensations by synthesizing equivalent stimuli is called a *colorimeter*. In this instrument one side of a photometric field is illuminated by the sample color. The other half of the field is then illuminated by controlled amounts of three primaries until the original color is exactly matched. Instruments vary widely in the method used to obtain the combination of colors for the match. The results are necessarily subjective, varying with the color vision of the observer. (Instruments used in chemistry to match the colors



of two solutions by varying the depth of one are not colorimeters, strictly speaking; they do not synthesize a color but merely compare two colors.)

Although any three primaries<sup>8</sup> can be chosen for a color match, for purposes of convenience in computation and standardization, a definite set was agreed upon by the International Commission on Illumination. These primaries will be designated by the symbols  $\bar{x}$ ,  $\bar{y}$ ,  $\bar{z}$ , which are called *tristimulus functions*. If one side of the field of the colorimeter is illuminated by unit quantity of radiant energy of the various wave lengths, the color at each wave length can be matched by adding to the other side of the field definite quantities of  $\bar{x}$ ,  $\bar{y}$ , and  $\bar{z}$ . In Fig. 298  $\bar{x}$ ,  $\bar{y}$ , and  $\bar{z}$  are represented graphically. The colors  $\bar{x}$ ,  $\bar{y}$ , and  $\bar{z}$  are not found in nature. They were adopted to overcome the difficulty of matching purple. In order to match purple with a colorimeter it is necessary to add one of the primaries to the side of the field that is being matched. This is equivalent to a negative value of one of the primaries. To avoid the use of negative values, a special set of primaries was chosen. Each of the three hues possesses a saturation greater than that found in nature.  $\bar{x}$  is a reddish purple,  $\bar{y}$  a green, and  $\bar{z}$  a blue. The values of  $\bar{x}$ ,  $\bar{y}$ , and  $\bar{z}$  required to match some of the wave lengths are given in Table 32.

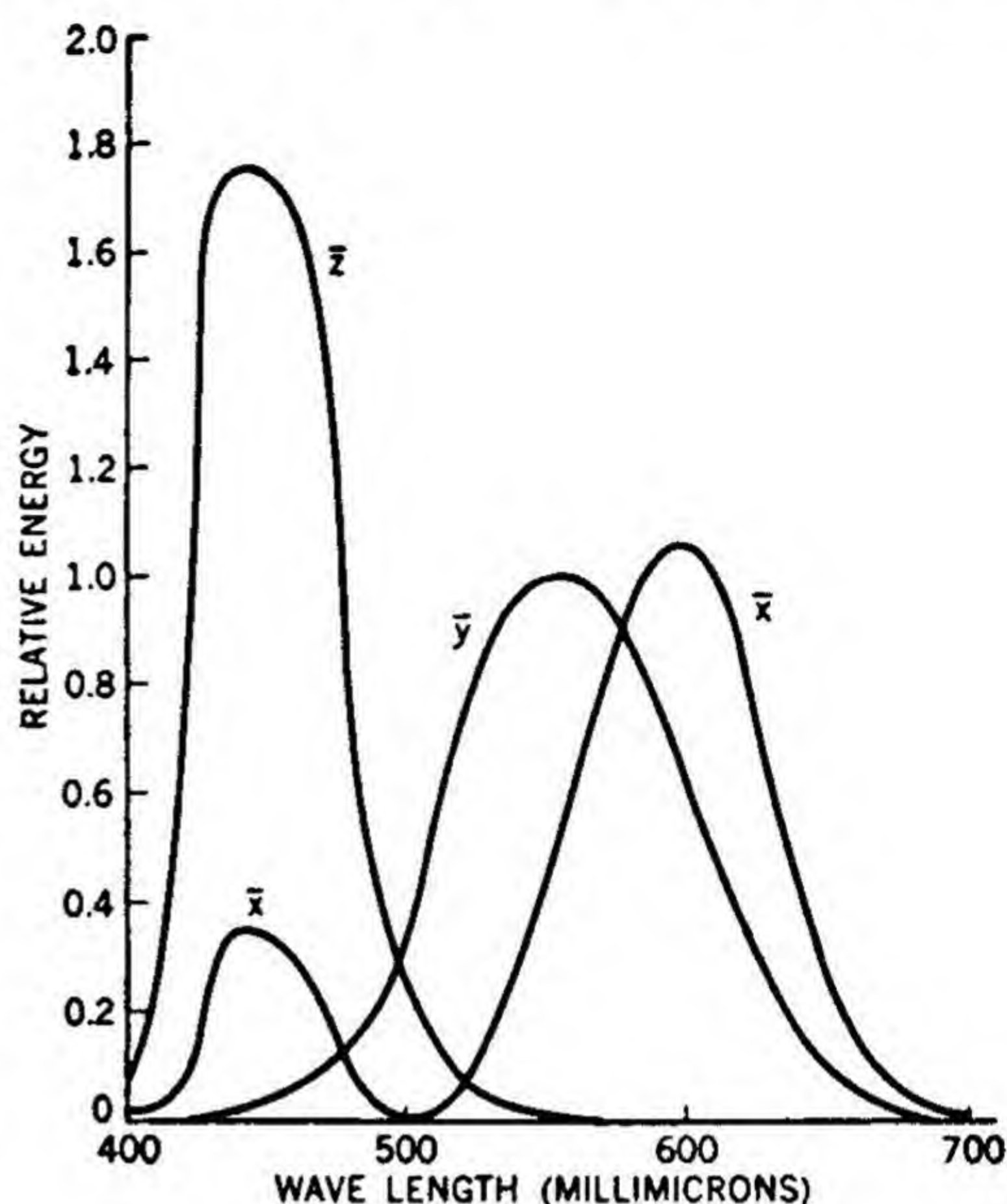


Fig. 298. Tristimulus functions.

TABLE 32. Tristimulus Values

WAVE LENGTH IN Mμ	$\bar{x}$	$\bar{y}$	$\bar{z}$
400	0.0143	0.0004	0.0679
450	0.3362	0.0380	1.7721
500	0.0049	0.3230	0.2720
550	0.4334	0.9950	0.0087
600	1.0622	0.6310	0.0008
650	0.2835	0.1070	0.0000
700	0.0114	0.0041	0.0000

These data were determined by a large number of reliable observers. They can be used together with spectrophotometric data to determine for any sample the tristimulus values which would have been obtained had the experiment been performed with a colorimeter by this group of observers. The desired objectivity is thus achieved.

To designate the amount of the three primaries required to match the color of an ink, paint, or paper, the symbols  $X$ ,  $Y$ , and  $Z$  are used. The symbols  $\bar{x}$ ,  $\bar{y}$ ,



and  $\bar{z}$  are restricted to spectrum colors; i.e., they are the  $X$ ,  $Y$ , and  $Z$  of spectrum colors. For a given color it is possible to assign for each unit millimicron of energy a coefficient for  $\bar{x}$ ,  $\bar{y}$ , and  $\bar{z}$ . By integrating these values we obtain the numbers  $X$ ,  $Y$ , and  $Z$ . We shall see how this integration is accomplished later.

Before leaving the subject of the selection of primaries, it should be mentioned that the primaries are so chosen that the  $\bar{y}$  function corresponds to the visibility function illustrated in Fig. 116. The  $\bar{y}$  value is, consequently, a measure of the brightness of the sample. Thus, if two colors can be represented by  $X = 50$ ,  $Y = 40$ ,  $Z = 60$ , and  $X' = 25$ ,  $Y' = 20$ ,  $Z' = 30$ , respectively, the fact that the value of  $Y$  is twice that of  $Y'$  indicates that the first sample is twice as bright as the second. The quality or chromaticity (explained later) of the two colors is the same; they differ only in brightness. The visibility or  $\bar{y}$  function gives the relative brightness of any color, perfect white having a value of 100 and perfect black a value of 0. Thus our first color above has a brightness relative to the white standard of 40 per cent.

## 6. TRICHROMATIC COEFFICIENTS

In order to conveniently specify colors, it is desirable to represent them graphically. To represent the tristimulus values  $X$ ,  $Y$ , and  $Z$  graphically would require a three-dimensional graph. The use of certain ratios, however, enables us to represent a color in two dimensions with cartesian coordinates. The coordinates are called *trichromatic coefficients* and are defined as follows:

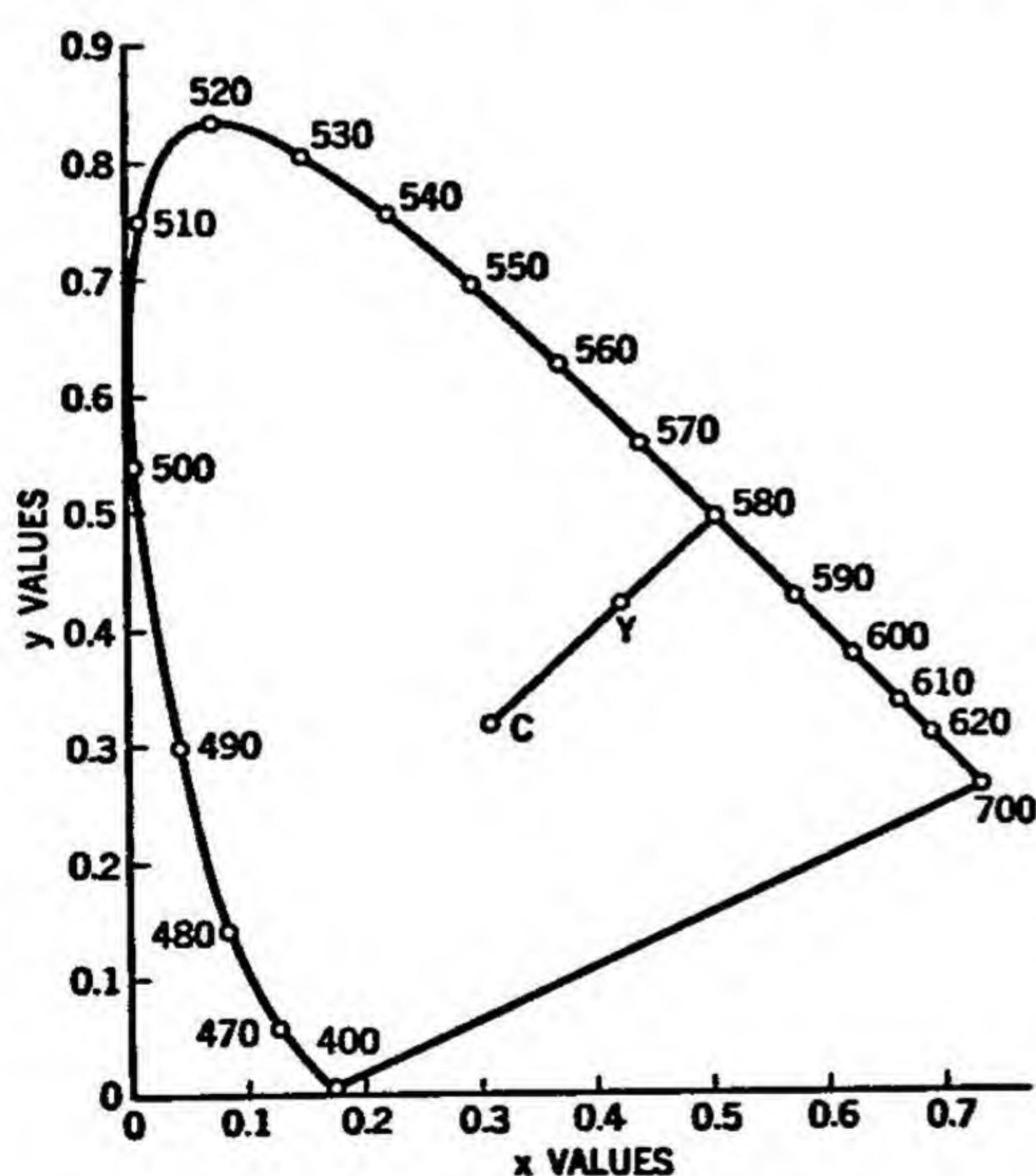


Fig. 299. The color triangle.

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z}$$

We have only two independent variables, since  $x + y + z = 1$ . Hence only two of the ratios, viz.,  $x$  and  $y$ , need be plotted. These two quantities are said to specify the *chromaticity* of a sample. They give no indication of the luminosity or brightness of the color. We have, however, seen that the value of  $Y$  indicates the brightness of a color. By giving the values of  $Y$ ,  $x$ , and  $y$  we can completely specify a color.

If the values given by the I. C. I. table (see Table 32) are used to evaluate  $x$  and  $y$  ( $x = \frac{\bar{x}}{\bar{x} + \bar{y} + \bar{z}}$ ,  $y = \frac{\bar{y}}{\bar{x} + \bar{y} + \bar{z}}$ ) for the spectrum colors, the so-called color triangle is obtained as illustrated in Fig. 299. This graph is called a



*chromaticity diagram.* All the spectrum colors lie on the solid line or indicated triangle. All other colors lie within the triangle. To locate 550 mμ, for example, we have merely to compute  $x$  and  $y$  using the values given in Table 32. Thus

$$x = \frac{\bar{x}}{\bar{x} + \bar{y} + \bar{z}} = \frac{0.4334}{0.4334 + 0.9950 + 0.0087} = 0.302$$

$$y = \frac{\bar{y}}{\bar{x} + \bar{y} + \bar{z}} = \frac{0.9950}{0.4334 + 0.9950 + 0.0087} = 0.692$$

The point  $x = 0.302$  and  $y = 0.692$  locates the spectrum color 550 mμ in the chromaticity diagram.

It should be noted that the color corresponding to *Illuminant C* lies at the center of the triangle. The primaries were chosen with this in view.

## 7. THE CHROMATICITY DIAGRAM

Several properties of the chromaticity diagram are of particular interest to us. We have seen that the value of  $Y$  indicates the brightness of a color. The other physical parameters, namely, dominant wave length and purity, can be deduced from the chromaticity diagram.

### Additive Mixtures

If the point  $Y$  corresponding to a yellow color in Fig. 300 is connected with the point  $G$  corresponding to a green color, the line joining these points is the locus of all colors obtained by mixing  $Y$  and  $G$  in different proportions. It follows from this that all real colors lie within the triangle, since all lines connecting spectrum colors lie within the triangle and all colors can be considered as mixtures of the spectrum colors.

### Dominant Wave Length

If the point  $Y$  is connected with the point  $C$  and the line extended to the triangle representing spectrum colors, then the intersection of this line with the triangle gives the dominant wave length. From what has been said above concerning additive mixtures, it may be seen that any color can be considered as a mixture of white light (*Illuminant C* in this example) and a spectrum color, i.e., monochromatic light of a certain wave length — the dominant wave length.

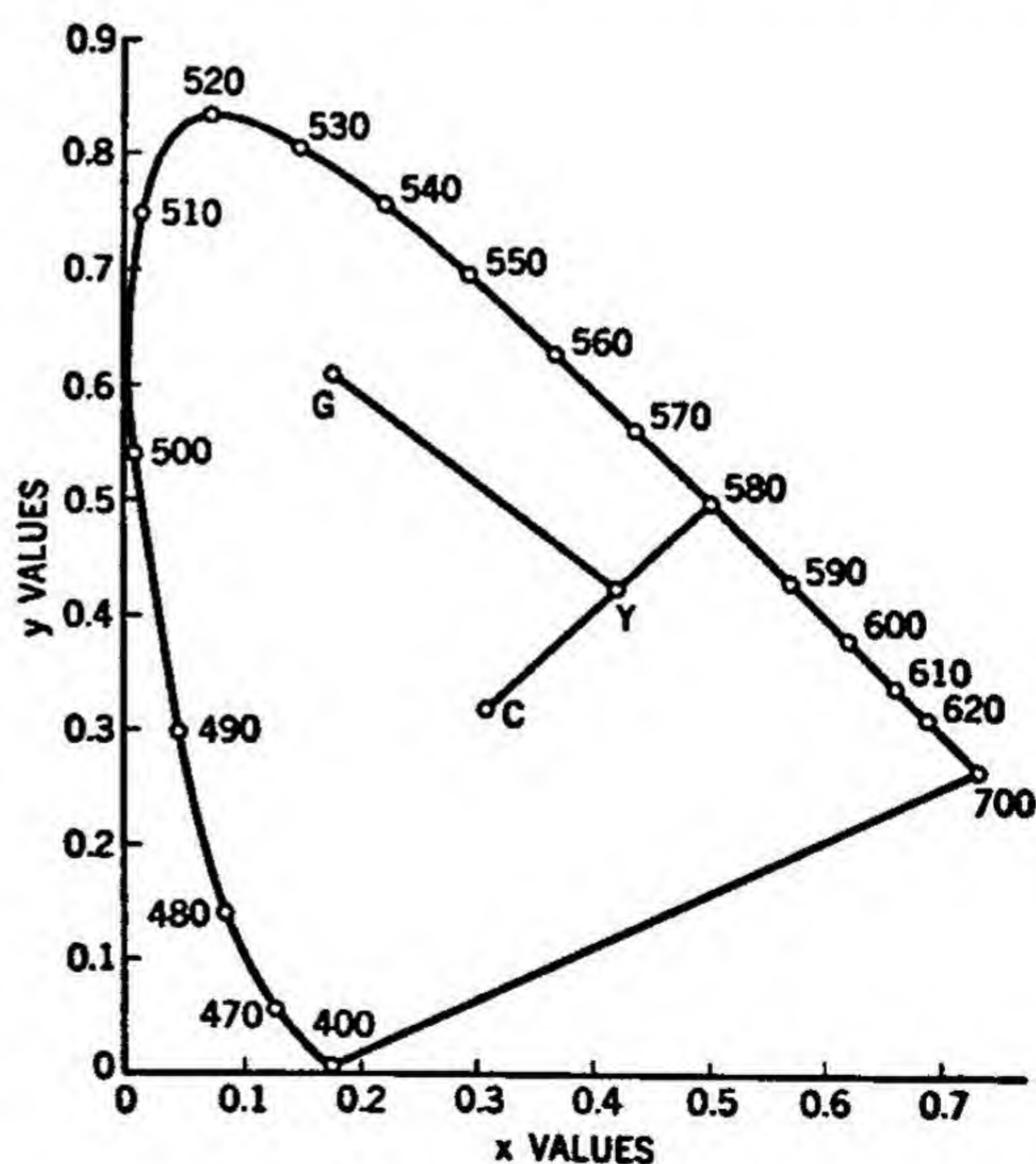


Fig. 300. Combining colors.



### Purity

The "pure" colors lie on the spectrum color triangle. Colors of lesser purity lie within the triangle. The purity of a color is determined by its position on the line joining the spectrum color and the illuminant point,  $C$ . If, for example, a point is halfway between the spectrum color and  $C$ , its purity is 50 per cent. In Fig. 299 the distance of point  $Y$  from point  $C$  is 60 per cent of the distance from point  $C$  to the spectrum color locus; hence its purity is 60 per cent.

## 8. COMPUTING TRICHROMATIC COEFFICIENTS FROM SPECTROPHOTOMETRIC DATA

We are now prepared to specify a color (i.e., to give the values of  $X$ ,  $Y$ , and  $Z$ ) by means of spectrophotometric data. The data given by the spectrophotometer are represented in Fig. 295. Here we have  $R$ , the reflectance, of a sample for each wave length. In Fig. 297 the energy distribution,  $E$ , of the source by which the sample is illuminated is given as a function of the wave length. The amount ( $X$ ,  $Y$ , or  $Z$ ) of each primary ( $\bar{x}$ ,  $\bar{y}$ , or  $\bar{z}$ ) required for a color match is then given by

$$\begin{aligned} X &= \int_0^{\infty} E_{\lambda} R_{\lambda} \bar{x}_{\lambda} d\lambda \\ Y &= \int_0^{\infty} E_{\lambda} R_{\lambda} \bar{y}_{\lambda} d\lambda \\ Z &= \int_0^{\infty} E_{\lambda} R_{\lambda} \bar{z}_{\lambda} d\lambda \end{aligned}$$

The following explanation may further clarify these relations.  $E_{\lambda}$  is the amount of radiant energy of wave length  $\lambda$  impinging on the sample from the illuminant.  $R_{\lambda}$  is the relative amount of energy, expressed as a fraction, reflected by the sample at wave length  $\lambda$ . Therefore,  $E_{\lambda} R_{\lambda}$  is the amount of energy reflected by the sample at wave length  $\lambda$ . The quantity  $\bar{x}_{\lambda}$  is the amount of the first primary required to match unit amount of radiant energy of wave length  $\lambda$ . Therefore  $E_{\lambda} R_{\lambda} \bar{x}_{\lambda}$  is the amount of the first primary required in matching the radiant energy reflected by the sample at wave length  $\lambda$ . This, by definition, is  $X_{\lambda}$ . The function  $X_{\lambda}$  is thus calculated for all wave lengths (in practice, a selected number) and the sum computed. The result is the tristimulus value  $X$ . The same procedure is followed for  $Y$  and  $Z$ .

Since the integrand is not a simple function, the integral must be computed by finite sums between definite wave lengths, viz.,

$$\begin{aligned} X &= \sum_{380}^{780} E R \bar{x} d\lambda \\ Y &= \sum_{380}^{780} E R \bar{y} d\lambda \\ Z &= \sum_{380}^{780} E R \bar{z} d\lambda \end{aligned}$$

The methods by which these summations are made are described by Hardy.<sup>9</sup>



Having computed  $X$ ,  $Y$ , and  $Z$ , we can evaluate  $x$  and  $y$ . The color is then specified by  $Y$ ,  $x$  and  $y$ .

## 9. COLOR MEASUREMENT

Although the present discussion consistently emphasizes the superiority of the spectrophotometer for forensic purposes, it should not be inferred that the other methods of color analysis are unreliable. There are many satisfactory techniques of color measurement in practical use today. It is worthwhile to describe some of these briefly since many police laboratories will be restricted to the use of one of the less costly instruments.

For our purposes we shall be concerned mainly with those instruments which will give us a specification of color in the I. C. I. system. Since the instruments which measure color by reflection will also measure color by transmission, we need discuss only reflection here. It should also be noted that in some of the instruments the observer can be replaced by a photoelectric device.

Following Mellon<sup>10</sup> we may classify color-measuring apparatus as follows: comparators, stimulimeters, and absorptometers.

### Color Comparators

These instruments are used in chemical analyses to determine the amount of a constituent present in a solution. They do not measure color as color, but simply enable the observer to compare the relative intensity of light transmitted through two tubes, one a standard and the other containing an unknown amount of the constituent. Beer's law (Chap. 13) is applied in the computations. The Duboscq comparator is the most widely used of instruments of this type.

### Color Stimulimeters

These are the instruments which are known as *colorimeters* to the physicist. Effectively, they enable the observer to match a given color stimulus by adding or subtracting controlled amounts of selected stimuli. The various methods of accomplishing this are employed in the instruments described below.

#### (a) ADDITIVE TRICHROMATIC COLORIMETERS

These instruments are based on the principle that any color can be matched by an appropriate mixture of three stimuli. One-half of a photometric field is illuminated by light reflected from the sample. The other half is illuminated by controlled amounts of three stimuli  $A$ ,  $B$ , and  $C$  the specifications of which are known in the I. C. I. system. The observer adjusts the amount of  $A$ ,  $B$ , and  $C$  until a match is achieved. The accuracy of the match depends to some extent upon the observer. There are many types of this instrument in use today. The Wright<sup>11</sup> and Donaldson<sup>12</sup> are two of the better known instruments. Figure 301 illustrates the essential parts of such a colorimeter.

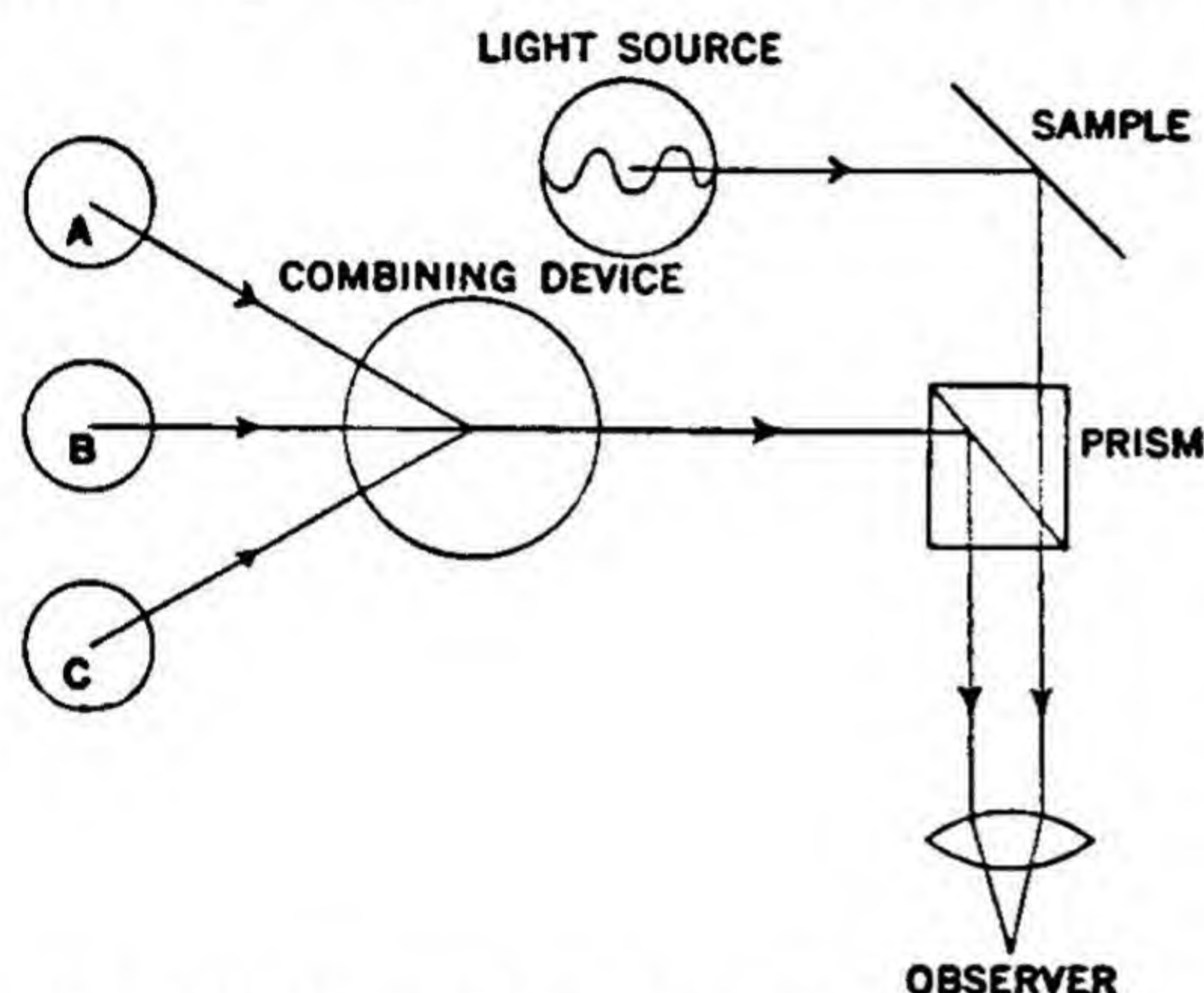


(b) *MONOCHROMATIC COLORIMETERS*

It was stated above that any color can be matched by a combination of white light and a spectrum color. This fact has provided the basis of another type of colorimeter in which one-half of the photometric field is illuminated by a mixture of white light of known specification and light of some known spectrum color. The method is not considered as reliable as the trichromatic method.<sup>13</sup>

(c) *SUBTRACTIVE COLORIMETERS*

Another method of matching a color is that of subtracting other colors from white light by means of filters. A three-variable system of filters is used as in



**Fig. 301. Illustrating the principle of the additive trichromatic colorimeter.**

additive colorimetry and for the same reason — the nature of the visual mechanism as it is known at present. In Chapter 39 the manner in which the color of light can be controlled by the use of a filter is described. In the matching of colors by the subtractive method, three filters are superimposed. Each filter absorbs a certain fraction of each wave length of the incident light. By subtracting in this manner from the intensity of the white light in selected spectrum regions, the spectral distribution of

the transmitted light can be made to approximate that of a given color.

The filters used in this process are blue-green, magenta, and yellow. These correspond to the red, green, and blue filters of additive colorimetry, the blue-green controlling the transmission of red, the magenta controlling green, and the yellow controlling blue. These colors are chosen because of the wide range of colors which they provide.

The Lovibond Tintometer is a subtractive type colorimeter which has been used by many handwriting experts in comparison of inks.<sup>14, 15</sup> Figure 223 is an illustration of the Bausch and Lomb instrument, in the design of which Albert S. Osborn collaborated. The filters used in this tintometer are glass slides, approximately blue, yellow, and red in color. A series of slides of each color is provided, varying in saturation. The ink specimen is placed before one chamber of the instrument. The slides are inserted in the other chamber under which is placed a white surface. By means of prisms the images may then be viewed through the ocular in one field.

When a proper choice of slides has succeeded in matching the color of the material under examination, the number of each slide is recorded. The slides of a given series are so numbered that a slide of a certain number is equal in effect to a set of slides the sum of whose numbers equals the number of the single slide.



In addition, the numbering is such that, if the same number slide is selected from each series, the three when viewed against a white background will yield a gray.

There are several disadvantages in the use of the Lovibond Tintometer. First, there is the defect common to all subtractive colorimeters — lack of control over the absorption. Each filter will affect only the radiation which is presented to it by the preceding filter. Thus, the filters do not possess independent control. In addition there is no continuity in a series — the observer must go from one filter to the next in the series. Hence the accuracy of a match is limited even though a large number of slides is available. The Tintometer suffers also from the defects of all visual colorimeters. A fairly standard observer must be postulated for reproducible results.

A modification of this instrument permits the conversion of the Tintometer readings into trichromatic coefficients. Thus it is possible by means of this instrument to specify a color in the I. C. I. system.<sup>16</sup> Dominant wave length, colorimetric purity, and brightness can, of course, also be determined.

#### (d) *COLOR ATLAS*

In selecting a color for household use the ordinary painter's card of color chips is consulted. Similarly, many industries use a catalogue of color patterns for matching. These catalogues, however, cannot be employed for general use since, for example, the colors of cloth and of paint are not exactly comparable because of the different nature of the surfaces.

Color atlases are available which can be used for various purposes. Among these are the *Munsell Book of Color*, the *Dictionary of Color Standards*, the *Ostwald Colour Album*, *Code Universel des Couleurs*, *Baumann's neue Farbentonkarte*, and the samples of the *Textile Color Card Association*.

Since there are more than ten million distinguishable colors, an atlas of this type is by no means comprehensive. Another disadvantage is the inevitable fading or discoloring of the patterns with age and use.

#### **Color Absorptometers**

These instruments measure the light transmitted or reflected by an object at various wave length regions. An absorptometer consists essentially of a dispersing system; a means for permitting the light to travel by two paths, one of which includes the object being measured; and a device for measuring the intensity of the light transmitted. This last objective can be achieved by visual examination, photoelectric measurement, or photographically, the method varying with the instrument. The laws of Bouguer and Beer are applied in the interpretation of the measurements. By plotting the values of transmittance or reflectance obtained with the instrument against wave length, a characteristic curve can be obtained for the substance under analysis.

We may classify these instruments according to the means by which the light is restricted to definite wave length regions. The filter photometer accomplishes this by means of filters. A spectrophotometer employs a monochromator, thus



permitting the operator to restrict the light to narrow spectral bands. There are many types of spectrophotometers available commercially. Two of the more

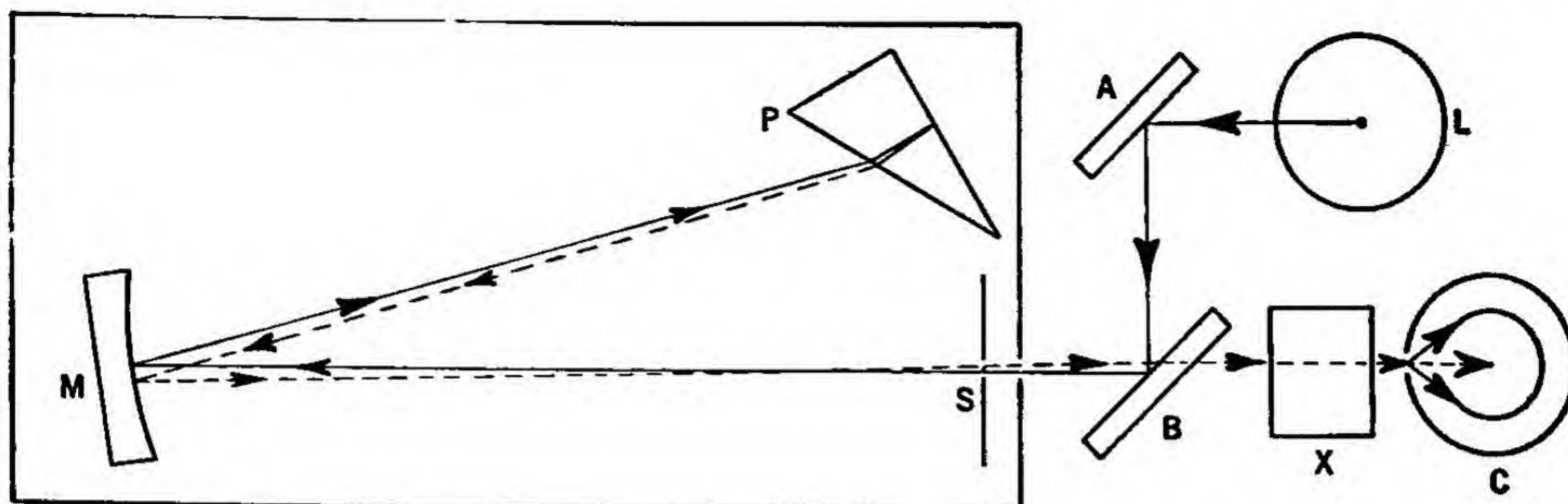


Fig. 302. Schematic diagram of the Beckman spectrophotometer.

important instruments are described below. Both of these measure reflectance as well as transmittance.

In Fig. 302 the Beckman spectrophotometer is shown schematically. Light from the source *L* is focused on the entrance slit *S* by means of a concave mirror *A* and a plane mirror *B*. A collimating mirror *M* reflects parallel light to the quartz prism *P* where it is dispersed and reflected back to the mirror, which in

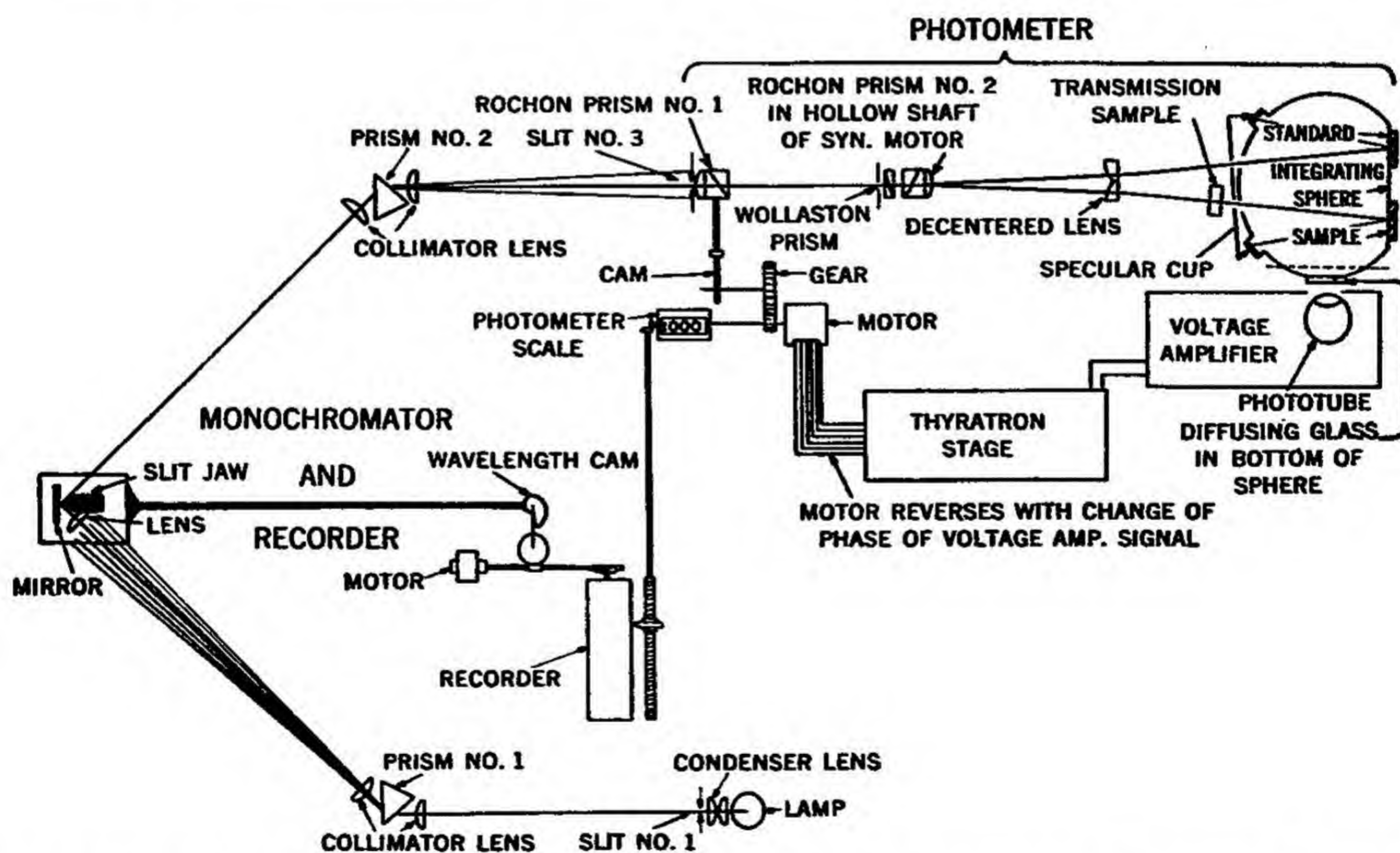


Fig. 303. Schematic diagram of the Hardy spectrophotometer. (Courtesy, General Electric Company.)

turn focuses it on the slit. *S* is a double slit; the light enters through the lower slit and emerges through the upper. The emergent beam passes through the absorption cell *X* into the photocell *C*. The prism is rotated to change wave length.



The Beckman instrument has several advantages in respect to range and monochromatization. It is calibrated from 200 to 2000  $m\mu$ . Measurements can be made from 200 to beyond 1100  $m\mu$ . Two photocells are used for this purpose



**Fig. 304. The Hardy spectrophotometer. (Courtesy, General Electric Company.)**

— one red-sensitive and the other blue-sensitive. The spectral band width can be made as narrow as 2  $m\mu$  or less depending upon the wave length used.

A more complicated instrument, but one which considerably shortens the operation time, is the Hardy spectrophotometer or color analyzer which is manufactured by the General Electric Company. This is an automatically recording spectrophotometer which employs the null method, i.e., a balance is obtained between intensities of beams traversing a path including the unknown and including the standard. Figure 303 is a schematic diagram of the instrument. Because of its complexity, an adequate description of the instrument would be too long to be included here. The Hardy spectrophotometer is limited simply to the visible and near infra-red region, 400 to 1000  $m\mu$ . The minimum spectral band width is 10  $m\mu$ . In these respects it differs from the Beckman instrument. The great rapidity of the Hardy instrument, however, its automatic recording



feature, and the relative ease with which reflectance and transmission measurements can be made are important advantages in the field of criminalistics.

## 10. SUMMARY

The aims of the police scientist in color analysis are (a) to compare colors and (b) to classify colors. Both of these aims are to be accomplished preferably by objective methods. Colorimeters are not the best answer because of their liability to variation of results with the color sense of the observer and with other factors. The spectrophotometer solves both problems in an objective way. The comparison of colors is achieved by comparing the reflectance (or transmission) curves of the two samples. Classification of colors is achieved by means of the reflectance curve of the sample, the energy distribution curve of the standard light source, and the I. C. I. tristimulus values. These functions yield the trichromatic coefficients by means of which the color is definitely labeled. The I. C. I. tristimulus values were determined colorimetrically by a large group of qualified observers. Thus they too may be considered as objective. Hence, the police scientist can classify colors by means of the spectrophotometer alone and does not require the use of the colorimeter.

## 11. APPLICATION OF THE SPECTROPHOTOMETER TO CRIMINALISTICS

### Comparison of Colors

When it is required to compare the colors of two cloths, for example, the operator has simply to determine the reflectance curves of the two samples to establish the identity or difference. Enlarged photographs of these curves can be used as exhibits in court. A simplified explanation to the magistrates and jury will enable them to understand the forensic value of these curves. In many cases where experts have testified, statements on the color of objects in evidence have been made purely on the basis of visual comparison. The objection of an informed opposing counselor can readily show the weakness of such testimony. Objections can be made also to testimony based on comparisons made with the colorimeter because of its subjective aspect. The spectrophotometric data, on the other hand, are much more reliable because of their greater claim to objectivity.

### Classification of Colors

The ability to specify colors by means of spectrophotometric data offers many opportunities to the police laboratory in the way of tracing submitted samples. It is expected that in the near future the wider use of the spectrophotometer in industry will lead to the common practice of color classification on the basis of I. C. I. data. Although industry is interested in color specification files mainly from the point of view of reproducibility, nevertheless such files will also serve the purpose of the criminalistician. For example, paints and dyes used in the various industries will be classified in this manner. When a colored sample



is submitted to the laboratory its color specifications can be determined spectrophotometrically. The industrial source of the sample can then be located by submitting the spectrophotometric data with a request that the manufacturer check his files for a paint or dye of these color specifications. In this way some part of the history of the material can be learned.

The following are some of the possible applications to specific materials:

### **Paints**<sup>17</sup>

An outstanding example of the use of paint as a clue is in an automobile accident. In an automobile collision flakes of paint are frequently shaken loose or are left adhering to some part of a second vehicle. By spectrophotometric data a comparison is possible between the paint found at the scene and the paint of a suspected car. If no suspected car is found, a trace can be made by means of the color specifications of the paint. The search can be made either by means of the files of automobile manufacturers or by means of files maintained at the laboratory. Because the present tendency among manufacturers is to use a standard type of headlamp, the sealed beam type, the identification of glass fragments in auto accidents becomes increasingly difficult. This fact enhances the importance of paint as a means of identification.

### **Inks**

The difficulties of a comparison by chemical analysis of inks of the same type used in writing a questioned document have been discussed in Chapter 34. Since the chemical properties are so difficult to determine, color, being the only determinable physical property, becomes of immense value in comparing or tracing an ink. A scientific police laboratory should endeavor to maintain a complete collection of inks together with their reflectance curves and color specifications.

Bailey and Casey<sup>18</sup> have investigated the changes which take place in ink marks on paper due to age. By means of spectrophotometric data they were able to show that washable inks remain practically the same in color over a period of several weeks. Permanent inks, however, vary considerably in their color changes. Some remain unchanged over this period after achieving their maximum contrast lightness in the first hour. Others reveal changes which vary from the slight to the profound. The change takes place chiefly in brightness ( $Y$ ). The dominant wave length remains fairly constant, but there is a general darkening with the passage of time.

### **Paper**<sup>19, 20, 21</sup>

The spectrophotometer suggests another approach to the problem of comparing papers and determining their age. Papers which appear equally white to the eye may possess different reflectance curves. Moreover, color specification provides an additional means of tracing colored stationery in document cases.



Using a Hammermill Ledger paper the following color characteristics were determined:

$x = 0.311$ ;  $y = 0.319$ ;  $Y = 71.6$  per cent;  
dominant wave length =  $564\text{ m}\mu$ ; purity = 1.0 per cent.

### Dyes

Color analysis of dyes can be made by means of the absorption spectrograph or the spectrophotometer. In spectrophotometry the transmission of the dye is measured as a function of its wave length. Two samples can be compared by means of these transmission curves. One particularly useful application of the color data of a dye is identification of detective dyes which are used to entrap thieves (Chap. 28).

### Cloth

An additional means of comparing two samples of cloth is offered by a color comparison. It may also be possible to trace the origin of a sample by means of its color specifications.

### Fibers and Hair

Fibers or hair found, for example, on a suspected vehicle in a hit-and-run case usually offer evidence of vital importance. Chemical analysis is frequently impossible in such cases because of the nature and quantity of the substance. A color comparison would give valuable information supplementing that obtained with the microscope. A difficulty in such a comparison by means of the spectrophotometer arises because of the small surface area of the sample. At present this difficulty has not been surmounted.

### Lipstick and Rouge

In many crimes of violence in which a woman is involved lipstick or rouge is rubbed from the woman's face and adheres to some part of the assailant's clothing or person. Sometimes a handkerchief or cigarette is found at the scene of the crime which bears the marks of a lipstick. The identification of a lipstick is a difficult problem. Spectrographic analysis will restrict the number of possible sources, but in general will not be conclusive. A color analysis is an invaluable supplement to the data of the spectrograph. Although the compositions of lipsticks may be similar, the colors are usually distinct, either because of the use of a different dye or of different proportions of ingredients.

### Gasoline

In Chapter 28 the problem of gasoline thefts was discussed. A method of detection suggested there involved use of fluorescent substances. An additional technique for identifying the gasoline by fluorescence is the use of spectrophotometric analysis. The complete color picture provides a convincing proof



### Quantitative Microanalysis

By measuring changes in spectral reflectance corresponding to changes in color of a solid highly reactive chemical reagent in the form of an opaque-type surface coating, it is possible to make quantitative microanalyses of substances such as carbon monoxide. Sendroy and Granville<sup>22</sup> have made use of the color reaction of palladium chloride with carbon monoxide (Chap. 30) to make quantitative determinations of the latter in air. By this method it was possible to measure carbon monoxide to within  $\pm 0.0002$  per cent in the lower range (0 to 0.01 per cent) and to within  $\pm 0.002$  per cent in the upper range (0 to 0.1 per cent).

### Narcotics

Absorption spectrophotometry provides another method of dealing with the analysis of narcotics. Figure 305 shows absorption curves obtained for samples of two related alkaloids. The infra-red region is found to be most useful for a sample of this nature.

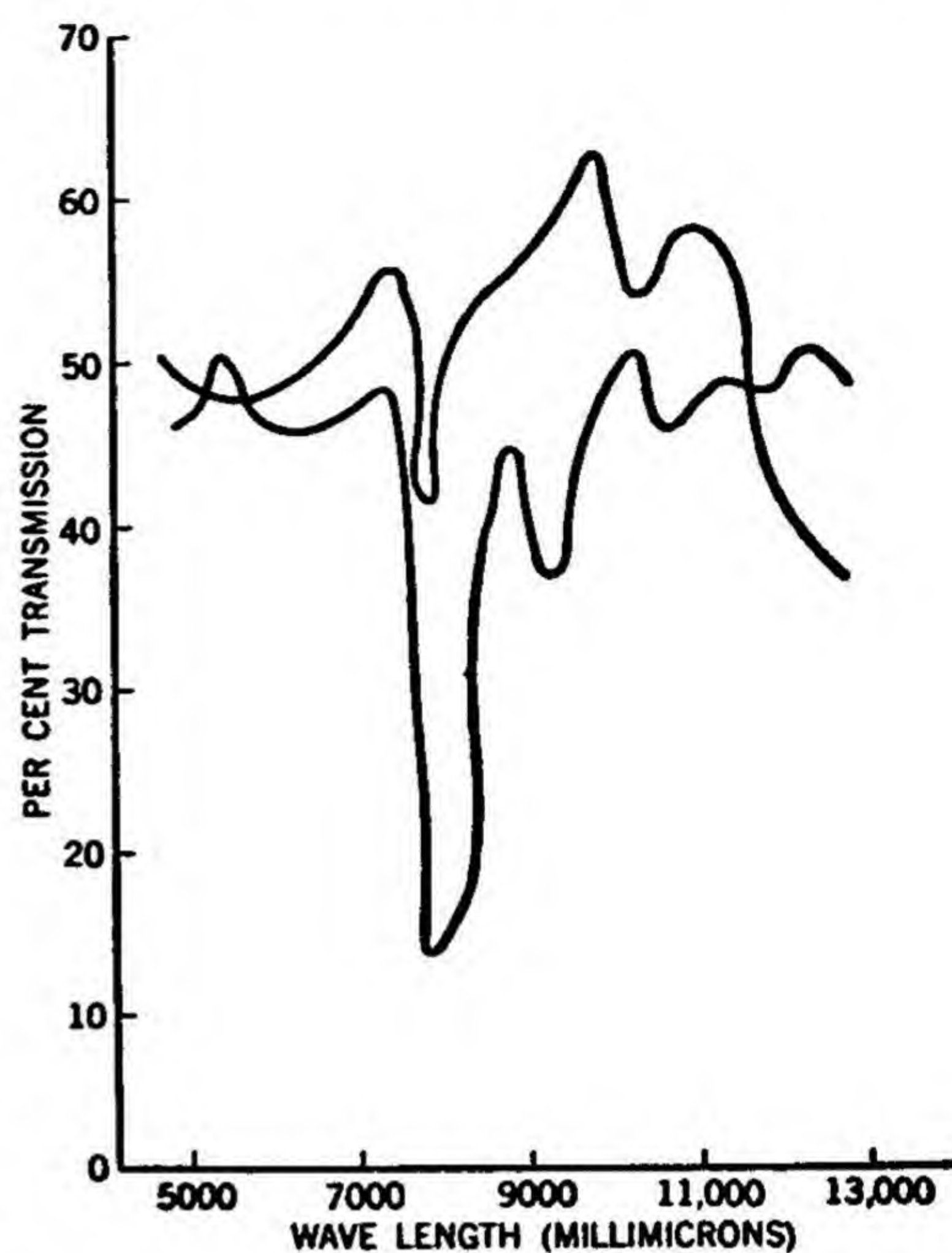


Fig. 305. Transmission curve showing difference between two related narcotics.

### Miscellaneous

A comparison of organic liquids can be greatly simplified by means of absorption spectrophotometry. The Beckman instrument is especially useful in detecting impurities in such liquids because of its high sensitivity in the ultraviolet region. The impurities will frequently contribute the conclusive evidence of the origin of a suspected sample.

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# CHAPTER 44

## THE ELECTRON MICROSCOPE

A development in science which offers a new method of identifying or analyzing substances always suggests an opportunity for the criminalistician. One of the most remarkable of recent developments of this nature has been the development of a practicable electron microscope. An entirely new microscopic world is being revealed through this instrument. The limit of useful magnification by means of the light microscope had been reached at approximately 2000X. The electron microscope, however, has been found capable of giving direct magnifications of from 50X to 20,000X. Useful magnification of 100,000X is possible with this instrument without employment of elaborate techniques. The limitations of magnification by the electron microscope have not yet been defined.

Naturally, this instrument has become a tool of great value to the sciences of physics, chemistry, and biology. The subdivisions of these sciences — medicine, bacteriology, synthetics, metallurgy, ceramics, plastics, and mineralogy — will no doubt be considerably advanced when the data of this submicroscopic world are interpreted. Criminalistics, which is a parasite of all these sciences, will enjoy comparable progress. It is for this reason that a short description of the electron microscope is included in this work. The applications of this instrument to the work of the police laboratory will be discussed at the end of this chapter.

### 1. LIMITATIONS OF THE LIGHT MICROSCOPE

The resolving power  $R$  of a microscope can be expressed by the following equation which is similar to equation (7) of Chapter 38:

$$R = \frac{\lambda}{2 N.A.} = \frac{\lambda}{2 n \sin \theta}, \quad (1)$$

where  $\lambda$  is the wave length of the light used,  $N.A. = n \sin \theta$ , numerical aperture,  $n$  is the refractive index, and  $\theta$  is the limiting angle of rays entering the lens. From this equation we see that resolution can be improved by increasing the  $N.A.$ , i.e., by increasing  $n$  or  $\theta$ , or by decreasing  $\lambda$ , the wave length of the light.



By increasing  $n$  and  $\theta$ , the oil immersion objective achieves a resolution of  $0.26 \mu$ . If we place the maximum value of  $N.A.$  with oil immersion objectives at 1.5, equation (1) is reduced to

$$R = \frac{\lambda}{3}.$$

Resolution now is expressed as a function of wave length alone. If we use visible light of wave length 6000 Å, the limit will be 2000 Å or  $0.2 \mu$ . By using the shorter wave lengths of the ultraviolet, 3000 Å, the smallest resolvable distance is reduced to 1000 Å or  $0.1 \mu$ . This, then, is the limit of resolution for the light microscope. If a means of employing radiations of shorter wave lengths is available, resolution can still be improved. It is precisely this which the electron microscope accomplishes — an increase in resolution by the use of radiations of extremely short wave lengths (in the region of  $10^{-9}$  cm).

## 2. THE ELECTRON WAVE

When a voltage is applied between a cathode and an anode in an evacuated tube, a stream of electrons is accelerated from the negative to the positive electrode. An opaque obstacle placed in the path will cast a shadow. The stream can be deflected by bringing a magnet close to the tube. An electrostatic field will also affect the stream.

This similarity between the phenomena exhibited by the electron radiation and light radiation led to the theory that these radiations were of the same nature. In the physical analogy, electrons exhibit the phenomena of interference and diffraction. To produce the refraction of electrons similar to that of light in glass, a nonmaterial lens consisting of an electrical or magnetic field of force is used. On passing through such a lens, electrons can be deflected and focused. Snell's law is found applicable. The velocity  $v$  of an electron discharge is proportional to  $\sqrt{V}$ , where  $V$  is the voltage applied between the cathode and anode. Since the refractive index  $n$  is proportional to velocity of light waves, it is logical to compare  $\sqrt{V}$  with  $n$ . Using  $\sqrt{V}$  as the refractive index for electrons it is found that Snell's law is obeyed.

Since the laws of refraction obtain, it would be expected that the laws of geometrical optics are true for electrons. It is found that the relation among focal length, magnetic field strength, and electron velocity fits the equation for the optical analogues of these terms.

## 3. THE ELECTRON LENS

The equation of light optics

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{F}$$

where  $p$  is the object distance,  $q$  the image distance, and  $F$  the focal length holds also for electron optics. In Fig. 306 the ordinary light lens is compared with a magnetic lens. The magnetic lens consists essentially of a solenoid encased in



soft iron. The magnification is equal to  $q/p$  and can be controlled by varying  $p$  as in light optics. The more common method of controlling magnification, however, is that of changing the focal length. The focal length of the magnetic lens depends upon the intensity of the current flowing through the windings of the solenoid. Changing the intensity of the current may also be used as a means

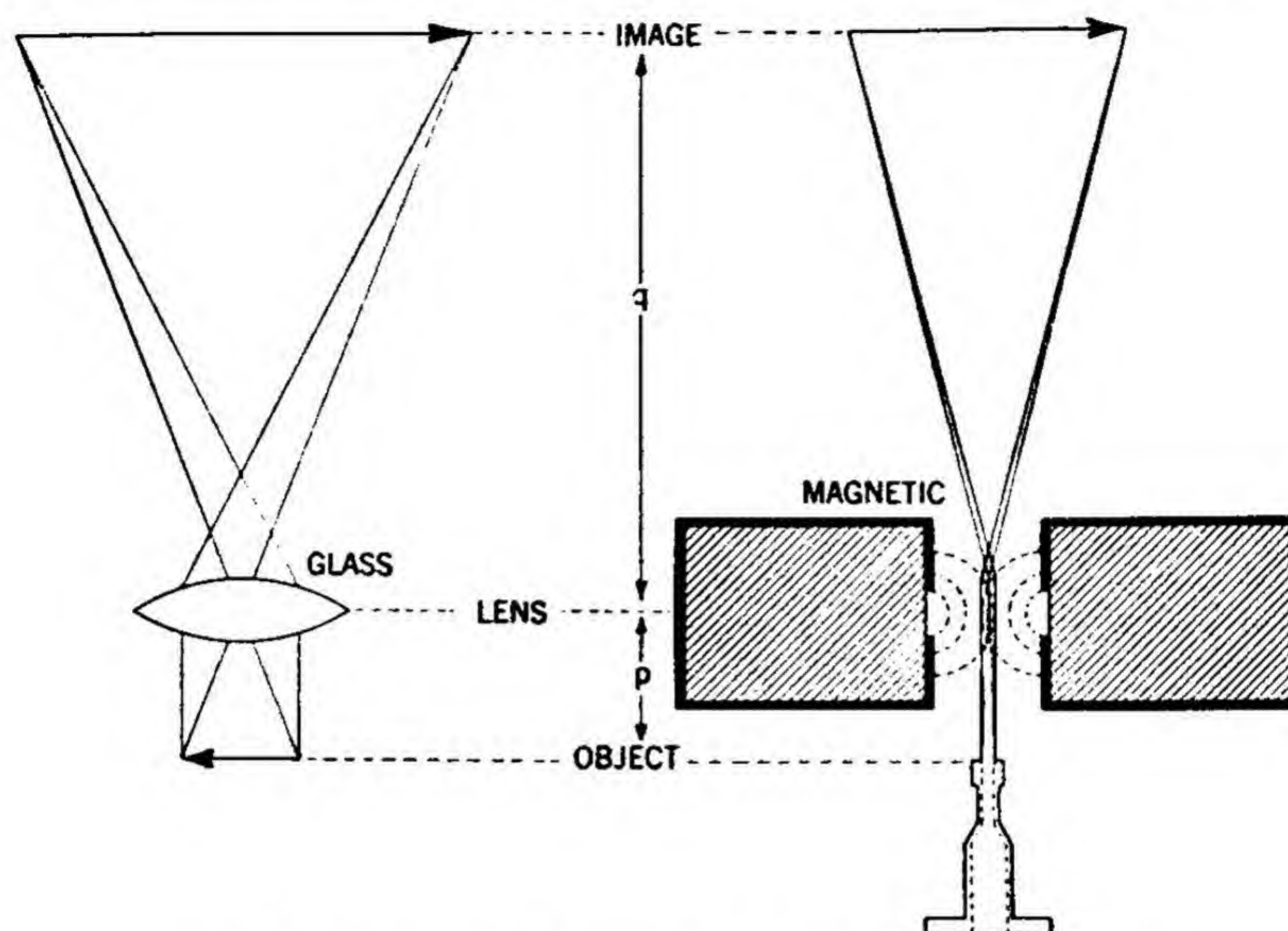


Fig. 306. Comparison between light and electron lenses.

of focusing the image. Fluctuations of this current must be kept at a minimum. The focal length of the lens depends also on the velocity of the electrons impinging on the object. Since this velocity is a function of the accelerating potential between the cathode and anode, the voltage must also be kept constant.

As with light lenses, the paraxial rays entering the electron lens suffer less aberration than the outside rays. Only a very small aperture can be used with the electron lens. Consequently  $\sin \theta$  of equation (1) is quite small. Limitations on voltage also result in a small refractive index. Thus  $n \sin \theta$ , the numerical aperture, has a considerably smaller value than that of light microscopes. In the light microscope this condition works against improved resolving power. However, the much smaller wave length used in the electron microscope more than compensates for this failing and results finally in a far greater resolving power. The numerical aperture is limiting only under theoretical conditions. This is because electrons entering the specimen are deflected or scattered in passing through it, and as a consequence the final image is the pattern of these focused electrons. The numerical aperture would be important if we were able to operate close to the diffraction effects of the wave length used. For example, a 60,000 volt electron has a wave length of 0.05 Å, but we do not obtain results near this in resolution. A resolution of 20 Å is considered quite good. In fact, recent work has shown certain types of specimens to give better resolution than others because of the variation of scattering power with density.



Another great advantage of the electron microscope is its extraordinary depth of field. In Chapter 38 the following equation for depth of field  $d$  was given for the light microscope:

$$d = \frac{\lambda \sqrt{n^2 - (N.A.)^2}}{(N.A.)^2}$$

Depth of field here varies inversely as the square of the numerical aperture, when the numerical aperture is small. Hence, although the shorter wave length, say  $\lambda = 52 \times 10^{-3} \text{ A}$ , works against increased depth of field; the fact that the  $N.A.$  is so small and enters in the second power results in a great increase in the depth of field. The following comparison between the two types of microscopes will illustrate these points:

TABLE 33

INSTRUMENT	N. A.	FOCAL LENGTH mm	USEFUL MAGNIFICATION	DEPTH OF FIELD A	RESOLU- TION A
Research microscope	0.95	4	800	80	2,600
Oil immersion objective	1.38	3	1,400	60	1,500
Electron microscope	<0.002	4	50,000	>10,000	4

Because of this increased depth of field in electron microscopy, stereograms are quite practicable. With the light microscope, stereoscopic photomicrographs are of value only at low magnifications where the depth of field is such that a change in stereoscopic viewing angle will reveal additional detail. At high magnifications the depth of field of the light microscope, particularly when it is used photographically, is so small that stereograms are worthless. Photomicrostereograms with the electron microscope are made by tilting the microscope between exposures.

#### 4. THE ELECTROSTATIC ELECTRON MICROSCOPE

The design of this instrument is such that the subject being studied is the emitting cathode. This microscope is especially useful for the study of metal surfaces. The necessity for etching and the possible loss of fine detail is avoided. The crystalline structure can be studied at various temperatures. Fine filaments can be photographed so that the die marks are visible.

The electrostatic electron microscope is comparable to the simple microscope or hand magnifier in that it possesses only one lens. Figure 307 is a schematic diagram of this instrument, comparing it with the light lens. A cathode emits a stream of electrons through the apertures of a grid and an anode, producing an image on a plate. The grid is similar to that of a three-electrode tube. The focal length (and magnification) of the instrument depend upon the ratio of the grid potential to the anode potential.

#### 5. THE MAGNETIC ELECTRON MICROSCOPE

This instrument (Fig. 308) corresponds to the compound microscope used with light waves. The magnetic type is at present in wider use than the electro-



static type. Like the light microscope it produces an image of an object by passing radiations through a thin transparent layer. The parts of this micro-

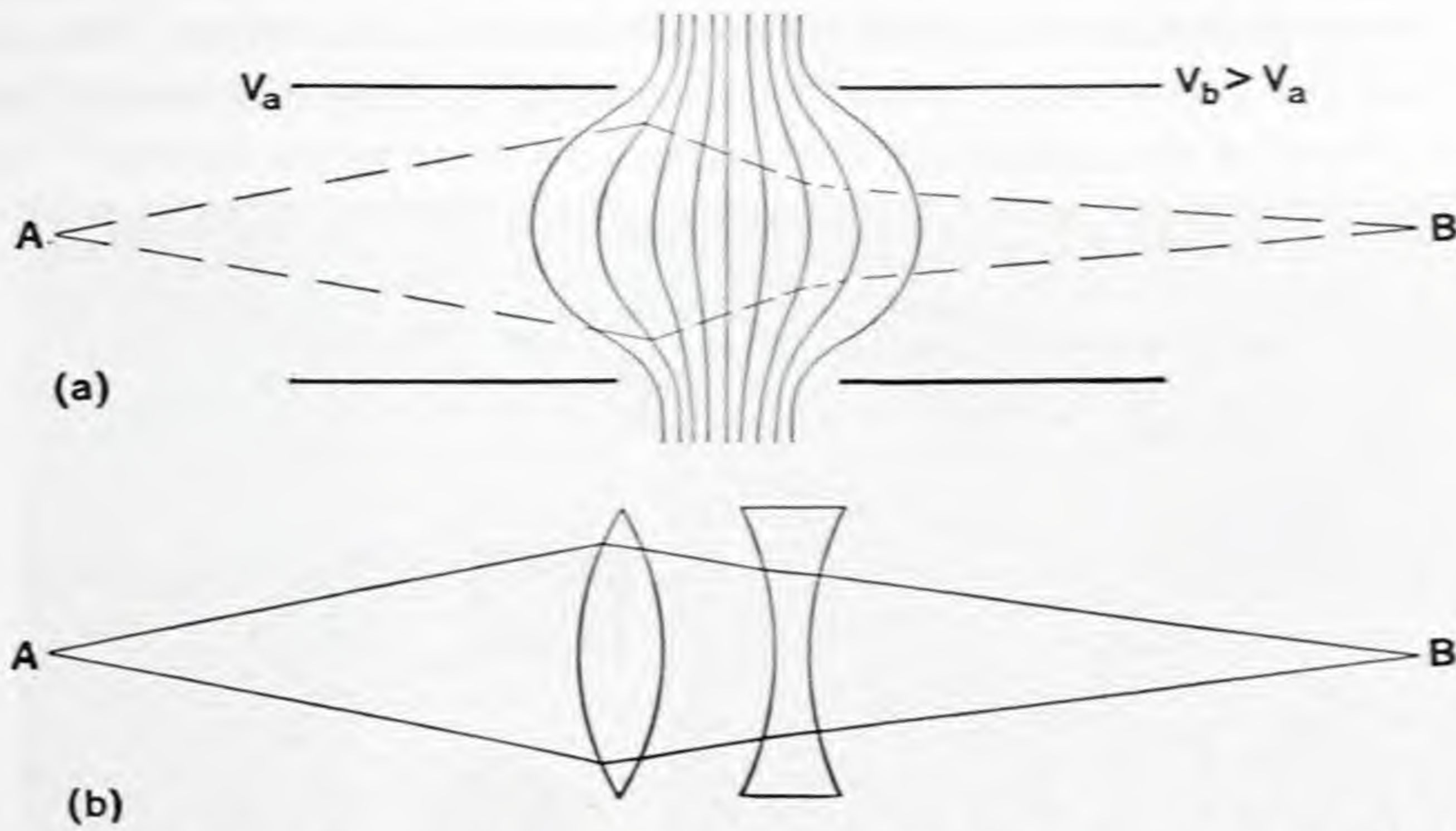


Fig. 307. Focusing action of (a) the electrostatic lens and (b) a light lens.

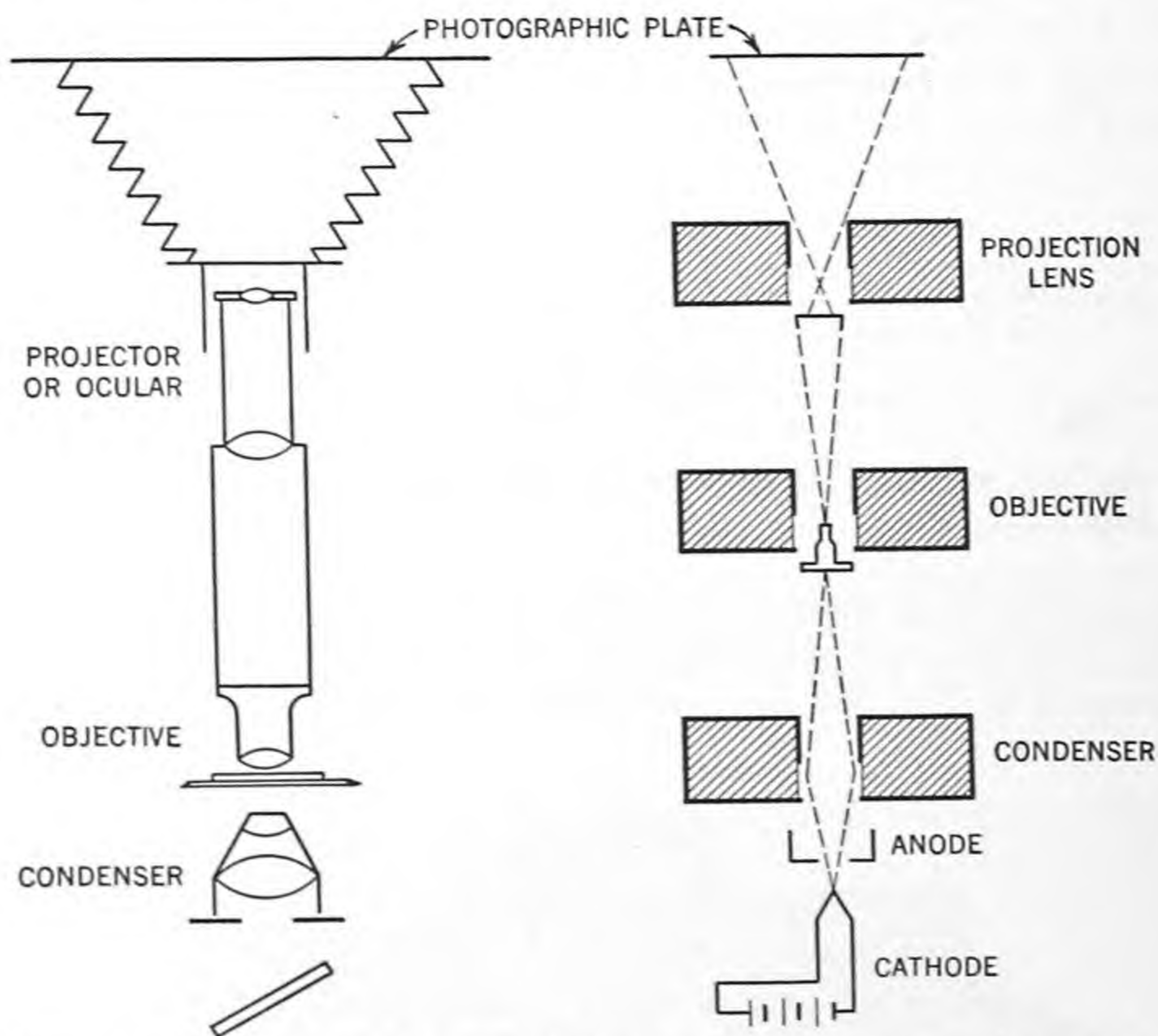
scope are analogous to those of the light microscope. Three lenses are used: a condenser, objective, and projector lens. All of these are magnetic lenses of the type illustrated in Fig. 306, i.e., solenoids mounted coaxially with the instru-



Fig. 308. Electron microscope-Console model. (Courtesy, Radio Corporation of America.)



ment. In Fig. 309 the magnetic electron microscope and the light microscope are compared. An electron source such as a cold cathode or hot filament directs a stream of electrons past the anode and through the condenser lens, which converges the stream into a narrow beam directed at the object. The electrons scattered from the object are focused by the objective lens to a magnified image in the focal plane of the projector lens, which in turn forms another magnified image on the fluorescent screen or photographic plate.



**Fig. 309. Comparison between the light and the electron microscope.**

The image formed by the objective lens is at a magnification of about 100X. This magnification is of the same order as that produced by the light microscope. The resolving power, however, of the electron microscope is such that a far greater subsequent magnification by the projector lens is justified. A magnification of 200X by the projector lens can be used as compared with 20X with the eyepiece of the light microscope. A useful magnification of 20,000X is thus achieved, which can subsequently be enlarged photographically several times. Magnifications between 4000 and 10,000X have been found most practical from the standpoint of exposure time, image brightness for focusing, and size of field.

The average electron microscope has sufficient intensity of beam so that any magnification is intense enough to produce exposures of reasonable times. In the latest type instruments, with optical focusing magnifiers, even image brightness is sufficient at most magnifications. The most important factors are: first, sufficient magnification to see what is being focused, and second, to make the



magnification as low as practical in order to include as much information as possible in the field. The field is usually fixed by size of the image screen or photographic plate, and as a consequence the operator should use barely enough magnification to see what he is trying to focus, and no more, so as to record maximum information on the plate.



Fig. 310. Electron microscope-Universal model. (Courtesy, Radio Corporation of America.)

## 6. DIFFICULTIES IN THE USE OF THE ELECTRON MICROSCOPE

(a) *Interpretation.* The interpretation of electron photomicrographs presents many difficulties. One of these is the smallness of the field, the great magnification, and the resulting isolation of an object from recognizable surroundings. In achieving the tremendous magnifications of the electron microscope, the operator is brought into an entirely new microscopic world. This difficulty can be met through bridging the gap between the light and the electron microscope



by lowering the magnification of the latter. It is possible to use the electron microscope at a magnification of less than 50X. This magnification can be produced by the light microscope and the two images can be compared. The operator can then reach higher magnifications in graduated steps which will always present him with familiar territory. The lower magnification of the electron microscope has been gradually reduced so that direct comparisons can be made electronically and optically, and the results interpreted accordingly. The extreme depth of field of the electron microscope often assists in better interpretation of light-optical results at these lower magnifications.

Another difficulty arises from the difference in the two types of radiation used. This results in a different appearance of the electron image. The lack of color in the electron image deprives the microscopist of another valuable aid in his work.

(b) *Operation.* The various parts of the electron microscope require constant care because of the fouling of various surfaces. An excellent vacuum must be constantly maintained in the instrument, since air impedes the passage of electrons. Variations in voltage and current must be kept at a minimum because of their great influence on focal length and focusing.

## 7. APPLICATIONS TO CRIMINALISTICS

The possibilities of the electron microscope in criminalistics are, at present, indicated by the research which is being conducted in industry, medicine, and biology. As the literature of this microscope develops, applications to the laboratory investigator's work will no doubt continually increase. Two general applications are possible: first, as an additional tool in the identification of a substance, chemically and physically, particularly where particle size, shape and distribution are important; second, as a means of determining under certain conditions the age of certain substances by minute changes in their structure. One of the chief problems of the police laboratory is the chemical analysis of minute quantities of matter which are submitted as evidence. The major tool for this work is the spectrograph; however, as we have seen, certain substances such as organic material, cannot be analyzed by the spectrograph. X-ray diffraction supplements the spectrographic analysis of crystalline substances revealing differences not indicated spectrographically.

The electron microscope is particularly helpful in relation to substances the analysis of which ordinarily depends upon a visual, microscopic examination. Thus, any study of material which can be furthered by increased resolution should be considered as a possible opportunity for the use of the electron microscope.

We may group subjects for electron microscopy into the following classes (1) sections cut from tissues and other materials; (2) ultrathin replicas of the surfaces of thick objects; and (3) suspensions of small cellular elements and of particles of colloidal and macromolecular dimensions.

The following are a few applications of this instrument in the police laboratory:



(a) *Metallurgy*. In some cases a small fragment of metal is found at the scene of the crime. If it is desired to compare this specimen with another specimen which is found in the possession of or which can be associated with the suspect, a spectrographic analysis can be made to determine the composition. However, where the number of trace elements are few and not unusual the

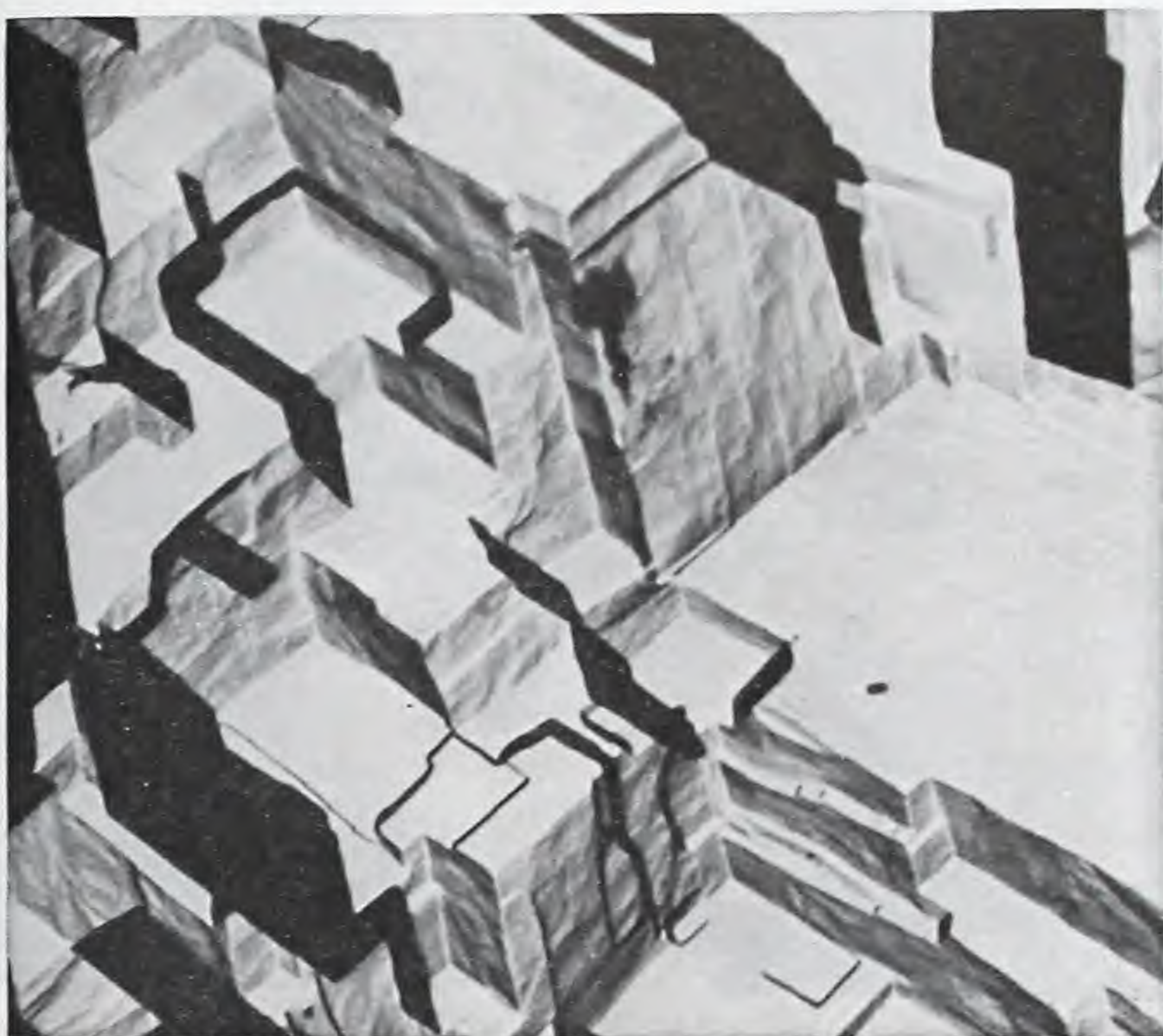


Fig. 311. Etched aluminum — 14,800X. (Courtesy, Dow Chemical Company.)

possibility exists that the specimens may not have come from the same source. A minute difference in crystal structure may or may not exist. An electron photomicrograph can be conclusive evidence here (Fig. 311).

In some cases of suspected sabotage such as the weakening and subsequent breaking of a vital metal part of a machine, a knowledge of the crystal structure is of vital importance. Crystal structure varies, too, in different layers of metal. The elimination of the necessity for etching makes the electron microscope a very powerful tool in these cases.

To show that two pieces of filament were cut from the same length of wire, an electron photomicrograph showing the marks of the die used on the wire offers strong additional evidence.

(b) *Dust*. In associating a suspect with the scene of a crime, discovery of characteristic dust or fragmentary particles is frequently of great importance. Face powder, mine dust, pollen, and many other minute traces can be left at or



borne from the scene of a crime by the criminal. The presence of similar material on the person or clothes of a suspect provides very strong evidence. The ultimate structure of many types of dust particles is not revealed clearly by the optical

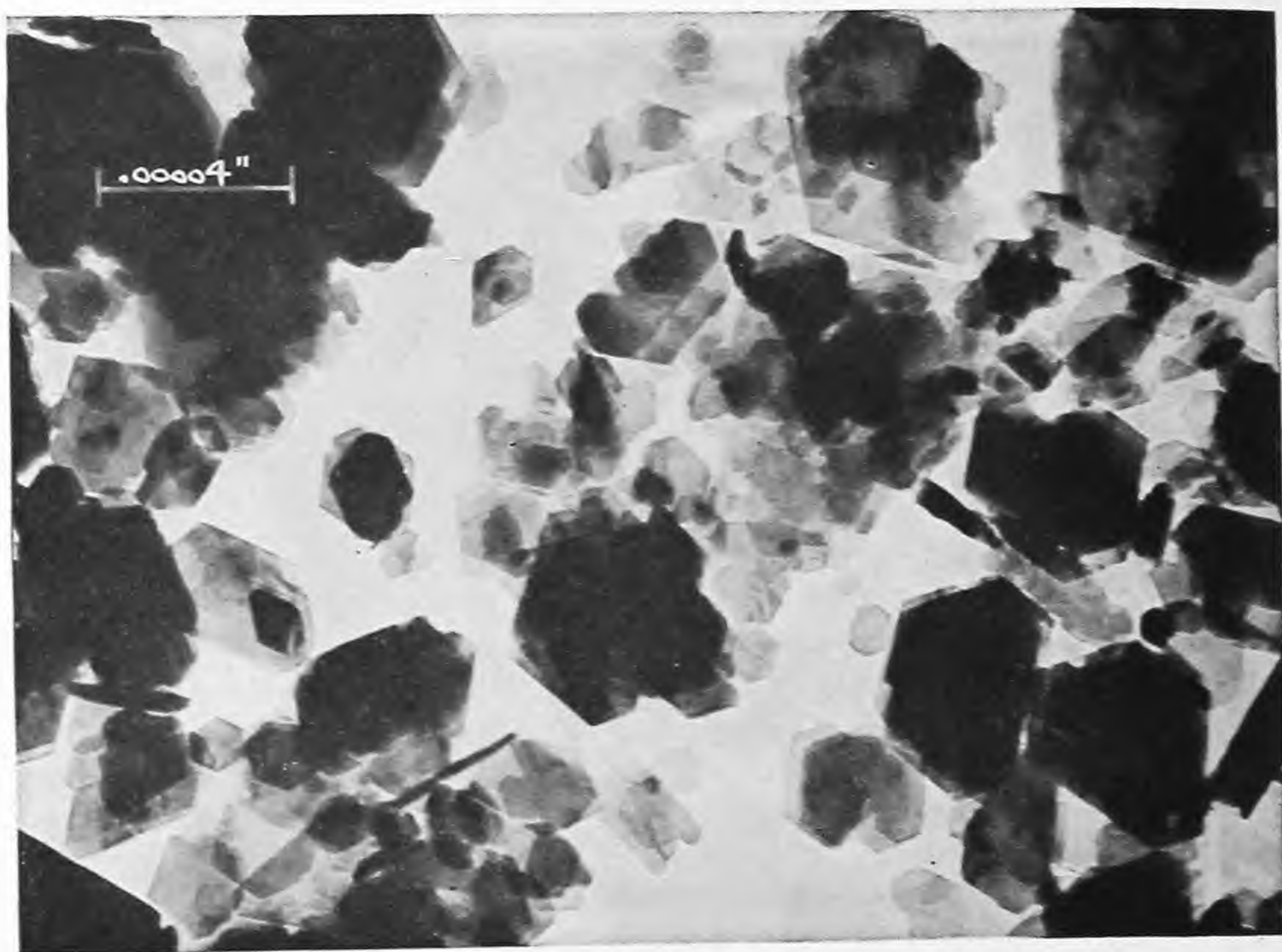


Fig. 312. Kaolin — 20,000X. (Courtesy, Radio Corporation of America.)

microscope. The shapes and size distribution of individual particles are also too minute for this instrument. Figures 312 and 313 are examples of electron micrographs of this class of material.

(c) *Fibers*. In crimes of violence a clue is frequently left in the form of fibers. A small sample of fiber cannot be readily analyzed chemically. Spectrography is of little assistance in the analysis of this type of organic matter. Reliance is usually placed in the visual microscope. However, cellulose fibrils and crystallites possess diameters of the order of 0.1 to 0.14  $\mu$ , which, as we have seen, is also the order of the limit of resolution of the light microscope. Hence the photomicrographic image is formed in part by diffraction effects. The absence, also, of any appreciable depth of field makes an adequate study of such fibrils and particles extremely difficult. Asbestos, wool, hair, and plastic fibers have already been studied with this instrument. It has been found particularly helpful in studying types of scales. Improved microtomes are being produced for cutting sections almost to one-tenth micron. This will be important in studying sections



of fibers. Dyed or stained fibers may be studied in cross section for observing penetration and structure.

(d) *Paper*. The study of paper may be considered a branch of the study of fibers. A problem frequently presented is that of determining whether two samples of paper came from the same source. By separating the sizing, fillers, and loading material from the fibers it is possible to study each microscopically. The revelation of fine structure and the enhanced depth of field possible with the electron microscope suggests its use in such a study. New techniques in shadow-casting are making it possible to examine paper surfaces. Barnes and Burton have developed a new method of making replicas of organic materials such as paper and cloth which will aid in this problem.



Fig. 313. Carbon black — 50,000X. (Courtesy, Radio Corporation of America.)

(e) *Inks*. The comparison and identification of inks is one of the classical problems of criminalistics. Chemistry and microscopy are usually inadequate in analyses of this nature. Electron microscopy will permit great magnifications of the ink particles, thus providing a method of distinguishing among inks by particle size and shape and of studying the changes of inks with age.

(f) *Pencil Writing*. The differentiation among pencil writings will be facilitated. The graphite, clay, and wax are abraded into the paper. Replicas of the paper can be made and studied.

(g) *Bullet Comparison*. Powder marks on the body or clothing of a person who has been shot may offer information concerning the type of ammunition which was fired. An electron microscope study of the unburnt powder will reveal significant characteristics which may identify the source of the powder used in a cartridge or permit its comparison with known powders.

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# PART J

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## SCIENCE AND THE PROBATIVE VALUE OF PHYSICAL EVIDENCE







# CHAPTER 45

## SOME USEFUL MATHEMATICS

In the work of the police scientist a knowledge of the mathematical theory of probability is of great importance. There is, first of all, the relatively minor application of the mathematics of probability to criminal cases involving gambling apparatus such as loaded dice or slot machines such as those described in Chapter 20. More important, however, is the fact that many subjects of police science are statistical studies which depend for their forensic value upon the laws of probability. The weight of testimony in questioned handwriting and firearms identification, for example, is drawn from the theory of chance. In general, wherever the problem is one of comparison between the known and unknown specimens, the criminalistician attempts to discover in the unknown a number of characteristics which correspond to characteristics of the known. From the existence of these common characteristics he argues to a common source because of the improbability of the independent occurrence of this set of characteristics.

An adequate discussion of probability must be prefaced by a brief treatment of permutations and combinations. The necessity of this may be readily seen. Probability deals with the number of possible outcomes of experiments in which all outcomes are considered "equally likely." A certain subset of these outcomes is of particular interest. For example, in a case involving loaded dice, tests must be made to determine any bias which the dice may possess. It is known that in a truly made die the probability of turning up one particular number is the same as that of turning up any other number. When two dice are introduced, the probabilities of combinations of numbers differ. If the dice are prejudiced toward seven and two, an investigation must be based on the probability of rolling this combination with true dice. The suspected dice must be rolled a great number of times and the results compared with the theoretical probability.

### 1. PERMUTATIONS

A set of  $n$  objects arranged in a particular order is said to be a *permutation*. For example, there are six different ways in which three flags  $B$ ,  $R$ , and  $G$ , can be arranged:  $RBG$ ,  $RGB$ ,  $BRG$ ,  $BGR$ ,  $GRB$ ,  $GBR$ ; hence we have six permutations.



The number of permutations of  $n$  things can be deduced by the following reasoning: the first place can be filled in  $n$  ways; the second in  $(n - 1)$  ways; the third in  $(n - 2)$  ways; the next to the last in 2 ways; and the last in 1 way. Hence the number is given by

$$n(n - 1)(n - 2) \cdots 2 \times 1 = n!$$

The symbol  $n!$  is called  $n$  factorial. The value 1 is assigned to  $0!$

If from a set of  $n$  objects we wish to know the number of arrangements  $A_r^n$  possible by taking them  $r$  at a time, the following formula is used

$$A_r^n = n(n - 1)(n - 2) \cdots (n - r + 1)$$

The derivation of this formula can be seen from the following examples:

**EXAMPLE 1.** How many three-letter code "words" are possible using the letters in the word "felony"? We have six letters to choose from. There are three places to fill. The first place can be filled in six ways; the second place in five ways; and the last place in four ways. For each of the six ways of choosing the first letter, there are five ways of choosing the second; hence there are  $6 \times 5$  or thirty ways of choosing the first and second letters. For each of these thirty ways of choosing the first and second, there are four ways of choosing the third. Hence, there are  $6 \times 5 \times 4$  or 120 ways of choosing the three letters. Therefore, 120 code "words" are possible from the letters of "felony."

**EXAMPLE 2.** In how many ways can 8 patrol posts be assigned to a platoon of 13 patrolmen? Since  $n = 13$  and  $r = 8$ , we have

$$A_8^{13} = 13 \times 12 \times 11 \times 10 \times 9 \times 8 \times 7 \times 6 = 51,891,840.$$

The calculations can be simplified by the use of logarithms (or by the use of log factorial tables) since  $A_8^{13}$  can be expressed also as  $\frac{13!}{5!}$ ; i.e.,

$$A_r^n = \frac{n!}{(n - r)!}$$

If we have a set of objects in which some of the objects are alike, the number of distinguishable arrangements is reduced. If, for example, we wish to know the number of possible arrangements of  $n$  objects,  $j$  of which are the same and  $k$  of which are the same, we have

$$A = \frac{n!}{j! k!}$$

**EXAMPLE 3.** How many code "words" are possible using the letters of the word "interconnected"? Since the letter  $n$  occurs three times,  $t$  twice,  $e$  three times, and  $c$  twice, we have

$$A = \frac{14!}{3! 3! 2! 2!} = 605,395,700.$$

## 2. COMBINATIONS

A selection of a group of  $r$  objects from a set of  $n$  objects without regard to order is called a *combination*. In the given example of forming three-letter code "words" from the letters of "felony," the words "lon" and "nol" are two different arrangements but the same combination. Obviously the number of combina-



tions is smaller than the number of permutations. From the formula for permutations we can easily deduce a formula for combinations. Any combination of  $r$  objects from a set of  $n$  objects can be permuted  $r!$  times. Hence for every combination of  $r$  things there are  $r!$  permutations. If we use the symbol  $C_r^n$  to represent the number of combinations of  $n$  things taken  $r$  at a time, we have

$$A_r^n = r!C_r^n$$

or

$$C_r^n = \frac{A_r^n}{r!}$$

which gives us

$$C_r^n = \frac{n(n-1)(n-2) \cdots (n-r+1)}{r!} \quad \text{or} \quad \frac{n!}{r!(n-r)!}$$

**EXAMPLE 1.** How many teams of two detectives can be chosen from a squad of ten?

$$C_2^{10} = \frac{10 \times 9}{2!} = 45.$$

**EXAMPLE 2.** In how many ways can a poker hand be dealt? Since there are 52 cards in the deck, 5 cards can be chosen in  $C_5^{52}$  ways. Thus,

$$C_5^{52} = \frac{52!}{5!47!} = 2,598,960.$$

**EXAMPLE 3.** In how many ways can a flush in clubs be dealt in a poker game? Since there are 13 clubs and a hand contains 5 cards, a flush in clubs can be dealt in  $C_5^{13}$  ways or

$$C_5^{13} = \frac{13 \times 12 \times 11 \times 10 \times 9}{5 \times 4 \times 3 \times 2 \times 1} = 1,287 \text{ ways.}$$

For flushes in any of the 4 suits we would have  $4 \times 1287$  or 5148 ways.

### 3. PROBABILITY

In probability we speak of events which can happen or fail in ways that are *equally likely*. The term "equally likely" does not necessarily imply that the events are not governed by physical laws, but indicates, rather, that the factors involved in determining the outcome are so complex or apparently beyond control as to justify our ascribing the result to *pure chance*. For example, the laws governing the flight of a flipped coin are well known, but the difficulty of controlling the flip so that the result will be predictable is very great. This difficulty of predictability justifies the use of the term *chance*, without denying the deterministic value of the laws of gross mechanics. Considerations of *extrasensory perception* need not concern us here.

If  $p$  denotes the probability that an event will happen,  $h$  the ways in which it can happen;  $f$  the ways in which it can fail; and if the  $h$  and  $f$  ways are all equally likely; then we take for our definition of probability the quotient

$$p = \frac{h}{h+f}.$$



If  $q$  is the probability of failure,

$$q = \frac{f}{h + f}.$$

Obviously,

$$p + q = 1.$$

If success is certain,

$$p = 1.$$

**EXAMPLE 1.** What is the probability of rolling a *four* with one die?

Since the die has six numbers,  $h = 1$  and  $f = 5$ ;

$$p = \frac{1}{1 + 5} = \frac{1}{6}.$$

**EXAMPLE 2.** In dealing five cards for a poker hand, what is the probability of getting exactly three clubs?

Since there are 13 clubs in the deck, 3 clubs can be drawn in  $C_3^{13}$  ways. The other 2 cards must be drawn from the remaining 3 suits or 39 cards. This can be done in  $C_2^{39}$  ways. Therefore a hand containing precisely 3 clubs can be drawn in  $C_3^{13} \times C_2^{39}$  ways. The total number of possible hands of any 5 cards is  $C_5^{52}$ . We have, then,  $h = C_3^{13} \times C_2^{39}$ ; and  $h + f = C_5^{52}$ . Hence,

$$p = \frac{C_3^{13} \times C_2^{39}}{C_5^{52}} = \frac{\frac{13!}{3! 10!} \times \frac{39!}{2! 37!}}{\frac{52!}{5! 47!}};$$

$$p = \frac{2,717}{33,320} \text{ or about 1 chance in 12.}$$

#### 4. INDEPENDENT EVENTS

We consider now the probability that two events will happen, given the number of ways in which each event can happen or fail independently. Since for each of the  $h_1$  ways in which the first event can occur, there are  $h_2$  ways in which the second can occur; the two events together can occur in  $h_1 h_2$  ways. Associating successes  $h_1$  and failures  $f_1$  of the first event with the successes  $h_2$  and failures  $f_2$  of the second event, we find that the total number of ways in which the two events can happen or fail is  $(h_1 h_2 + h_1 f_2 + h_2 f_1 + f_1 f_2)$ . The probability of the two events happening is

$$p = \frac{h_1 h_2}{h_1 h_2 + h_1 f_2 + h_2 f_1 + f_1 f_2},$$

which can be written as

$$p = \frac{h_1 h_2}{(h_1 + f_1)(h_2 + f_2)}.$$

but this is simply  $p = p_1 p_2$ . A similar result can be obtained for  $n$  events. We have, thus, the law of *compound probability*: The probability that two or more independent events will happen is equal to the product of their separate probabilities.



**EXAMPLE 1.** Calculate the probabilities of rolling the various numbers with two dice (i.e., calculate the odds for the various points on a single roll in an ordinary crap game.) Since there are six numbers on each die, the total number of ways in which any number can occur or fail in a roll is  $6 \times 6$  or 36. There is only one way of rolling a *two*, i.e., by rolling a *one* on each die. The probability is, therefore,  $1/36$ . To roll a *three* we must have the sum  $2 + 1$ . This can be chosen in two ways.  $p = 2/36$  or  $1/18$ .

The number *four* can be obtained from the sums  $3 + 1$  and  $2 + 2$ . The first of these can be chosen in two ways; the second in one way. Hence,  $p = 3/36$  or  $1/12$ .

For number *five* we have the sums  $3 + 2$  and  $4 + 1$ , each of which can be chosen in two ways; hence,  $p = 4/36$  or  $1/9$ .

For number *six* we have the sums  $1 + 5$ ,  $2 + 4$ , and  $3 + 3$ . Since the first two of these can be chosen in two ways each, we have  $p = 5/36$ .

For number *seven*, we have  $1 + 6$ ,  $2 + 5$ ,  $3 + 4$ , each of which can be chosen in two ways. Therefore,  $p = 6/36$  or  $1/6$ .

It is left for the reader to calculate the remaining probabilities. The obvious symmetry is seen in the following table.

NUMBER	2	3	4	5	6	7	8	9	10	11	12
PROBABILITY	$\frac{1}{36}$	$\frac{2}{36}$	$\frac{3}{36}$	$\frac{4}{36}$	$\frac{5}{36}$	$\frac{6}{36}$	$\frac{5}{36}$	$\frac{4}{36}$	$\frac{3}{36}$	$\frac{2}{36}$	$\frac{1}{36}$

**EXAMPLE 2.** What is the probability of rolling a *seven* four times in succession?

$$p = (6/36)^4 = 1/1296.$$

## 5. MUTUALLY EXCLUSIVE EVENTS

Given the separate probabilities of two events and given also that both cannot occur simultaneously (i.e., they are mutually exclusive) what is the probability that one of them will occur? We have here three possibilities: (1) the first event happens, the second fails; (2) the first fails, the second happens; (3) both fail. Since they are mutually exclusive, no two can happen. These three possibilities are represented respectively by  $h_1$ ,  $h_2$ , and  $(f_1 + f_2)$ . The number of ways in which either of the events can happen or fail is  $h_1 + h_2 + f_1 + f_2$ . The number of ways in which either of the events can happen is  $h_1 + h_2$ . Therefore the probability that one of the events will occur is

$$p = \frac{h_1 + h_2}{h_1 + f_1 + h_2 + f_2} = \frac{h_1}{h_1 + f_1 + h_2 + f_2} + \frac{h_2}{h_1 + f_1 + h_2 + f_2}$$

In other words the probability that one of several mutually exclusive events will occur is the sum of their separate probabilities.

**EXAMPLE.** What is the probability of rolling a *six* or an *eight* in one throw of the dice?

$$\text{For a six we have, } p_1 = \frac{5}{36}$$

$$\text{For an eight, } p_2 = \frac{5}{36}$$

$$\text{For either six or eight, } p = p_1 + p_2 = \frac{10}{36}$$



The following rules of probability are given here for the sake of completeness. These theorems are extensions of the principles already stated. The reader is referred to any textbook of college algebra for the proof of these scholia.

(a) The probability that an event will occur exactly  $r$  times in  $n$  trials is

$$C_r^n \times p^r (1 - p)^{n-r}$$

where  $p$  is probability in a single trial.

**EXAMPLE.** What is the probability of rolling a *seven* exactly three times in five throws of the dice?

From previous examples we know that the probability of rolling a seven in one trial is  $1/6$ . Since  $n = 5$  and  $r = 3$ , we have

$$p = C_r^n p^r (1 - p)^{n-r} = C_3^5 (\frac{1}{6})^3 (1 - \frac{1}{6})^2,$$

or 
$$p = \frac{5 \times 4 \times 3}{3!} (\frac{1}{6})^3 (1 - \frac{1}{6})^2,$$

which gives  $p = 125/3888$ , or about 1 chance in 31.

(b) If the probability that an event will happen on a single trial is  $p$ , the probability that it will happen at least  $r$  times in  $n$  trials is the sum of the first  $(n - r + 1)$  terms of the binomial expansion of  $(p + q)^n$ , where  $q = 1 - p$ .

Thus 
$$P = p^n + C_1^n p^{n-1} q + C_2^n p^{n-2} q^2 + \dots + C_{n-r}^n p^r q^{n-r}.$$

We are now prepared to calculate the probability of winning in a crap game. In this game two dice are rolled. If the player throws a 7 or 11 on the first roll he wins. If he throws a 2, 3, or 12 on the first roll he loses. If on his first throw he rolls a 4, 5, 6, 8, 9, or 10, he may continue to throw until he throws either the same number or a 7. If he throws the same number, he wins; but if he throws a 7, he loses.

In order to determine the probability of winning we shall compute the probability of winning on each roll and sum up the separate probabilities of these mutually exclusive events. The probability of winning on the  $n^{\text{th}}$  roll will be denoted by  $p_n$ . The total probability will be  $P$ .

To win on the first throw the caster must roll a 7 or 11; hence the probability of winning on the first throw is

$$p_1 = \frac{6}{36} + \frac{2}{36}$$

or 
$$p_1 = \frac{8}{36}.$$

To compute the probability of winning on succeeding throws we must treat the possibilities for each of the points 4, 5, 6, 8, 9, and 10 separately. The symbol  ${}_z p_n$  will represent the probability of winning by rolling the point  $z$  on the  $n^{\text{th}}$  throw. Thus  ${}_5 p_6$  denotes the probability of winning by rolling the point 5 on the sixth throw.

If the number of ways of throwing the point  $z$  is  $x$ , then the probability of winning on the second roll with point  $z$  is the product of the probabilities of throwing  $z$  on the first and second throw.



Hence

$${}_z p_2 = \frac{x}{36} \times \frac{x}{36}$$

or

$${}_z p_2 = \left(\frac{x}{36}\right)^2$$

The probability of winning on the third throw with point  $z$  is given by the product of the probability of throwing  $z$  on the first throw, which is  $x/36$ , the probability of throwing neither  $z$  nor 7 on the second throw, which is  $\frac{36 - (6 + x)}{36}$ , and the probability of throwing  $z$  on the third throw, which is  $x/36$ ;

Hence,

$${}_z p_3 = \frac{x}{36} \times \frac{36 - (6 + x)}{36} \times \frac{x}{36}$$

or

$${}_z p_3 = \left(\frac{x}{36}\right)^2 \left(\frac{30 - x}{36}\right)$$

For the fourth throw we have the product of the following probabilities: casting  $z$  on the first throw; neither  $z$  nor 7 on second and third; and  $z$  on the fourth. Hence,

$${}_z p_4 = \frac{x}{36} \times \frac{30 - x}{36} \times \frac{30 - x}{36} \times \frac{x}{36}$$

or

$${}_z p_4 = \left(\frac{x}{36}\right)^2 \left(\frac{30 - x}{36}\right)^2$$

The manner in which these probabilities are formed is now apparent. For the  $n^{\text{th}}$  throw the probability will be

$${}_z p_n = \left(\frac{x}{36}\right)^2 \left(\frac{30 - x}{36}\right)^{n-2}$$

The probability of winning on any throw after the first by means of point  $z$  is given by the sum of these probabilities. Thus the total probability  ${}_z p_n$  for point  $z$  in  $n$  throws is given by

$${}_z p_n = \sum_{i=0}^{n-2} \left(\frac{x}{36}\right)^2 \left(\frac{30 - x}{36}\right)^i \quad (1)$$

The total probability for winning not later than the  $n^{\text{th}}$  throw is given by

$$P_n = p_1 + {}_4 p_n + {}_5 p_n + {}_6 p_n + {}_8 p_n + {}_9 p_n + {}_{10} p_n.$$

Because of the symmetry previously remarked, we may write

$$P_n = p_1 + 2({}_4 p_n + {}_5 p_n + {}_6 p_n).$$

Or, by substituting  ${}_z p_n$  from equation (1),

$$P_n = p_1 + 2 \sum_{r=3}^5 \sum_{i=0}^{n-2} \left(\frac{x}{36}\right)^2 \left(\frac{30 - x}{36}\right)^i \quad (2)$$



( $x$  represents the ways in which any given point can be rolled; hence, it assumes the values 3, 4, and 5 for points 4, 5, and 6.)

Since the number of throws is unlimited we must find the value of

$$P = p_1 + 2 \sum_{x=3}^5 \sum_{i=0}^{\infty} \left(\frac{x}{36}\right)^2 \left(\frac{30-x}{36}\right)^i;$$

but

$$\sum_{i=0}^{\infty} \left(\frac{x}{36}\right)^2 \left(\frac{30-x}{36}\right)^i$$

is simply a convergent geometric progression having the value

$$\frac{x^2}{36(6+x)}.$$

Hence, we have

$$P = p_1 + 2 \sum_{x=3}^5 \frac{x^2}{36(6+x)}$$

or

$$P = \frac{8}{36} + 2 \left( \frac{9}{36 \times 9} + \frac{16}{36 \times 10} + \frac{25}{36 \times 11} \right)$$

The probability of winning, therefore, is

$$P = \frac{244}{495} \text{ or } 0.493.$$

Equation (2) can be used to calculate the probability for a limited number of throws.

In addition to its wide use in the fields of science, the theory of chance can frequently be applied with profit to the homely incidents of everyday life. The following example is given more for its value in suggesting the power of the theory than for any immediate practical guidance for the expert witness in preparing evidence.

**EXAMPLES:** 1. In a case of homicide the victim was known to have been murdered between 3:40 p. m. and 5:10 p. m., the period being fixed by the visits of tradesmen. It is also known that the deceased received in this time two telephone calls, which will be represented by the letters  $A$  and  $B$ . Call  $A$  is known to have preceded call  $B$ . What is the probability that call  $B$  occurred in the period from 4:30 to 4:45 p. m.?

We assume that  $B$  occurred within the interval  $dt$  approximately  $t$  minutes after 3:40 p. m.  $A$  is now restricted to a period of  $t$  minutes out of 90 minutes (3:40 subtracted from 5:10). We may restate this restriction by saying that the number of possible ways of fixing the time of  $A$  is proportional to  $t$ . Similarly, the number of possible ways of fixing  $B$  is proportional to  $dt$ .  $A$  and  $B$  together can be fixed in  $ktdt$  ways, where  $k$  is a proportionality constant. The number of ways in which  $B$  could happen between 4:30 to 4:45 can be found by integrating  $ktdt$  between the limits 50 and 65 which represent the time in minutes if 3:40 is considered the zero point. Calling the number  $h$ , we have

$$h = k \int_{50}^{65} t dt.$$



The total number of ways  $(h + f)$  of fixing  $B$  in the 90 minutes would then be

$$h + f = k \int_0^{90} t dt.$$

The probability is then given by

$$p = \frac{k \int_{50}^{65} t dt}{k \int_0^{90} t dt} = \frac{t^2 \Big|_{50}^{65}}{t^2 \Big|_0^{90}} = \frac{23}{108}.$$

The probability that call  $B$  occurred between 4:30 and 4:45 is approximately one chance out of five.

From the form of the integral it can be seen that the probability becomes less as the period is placed more nearly 3:40. We can study this variation by writing the integral of the numerator with the general limits  $x$  and  $y$ . Thus,

$$p = \frac{t^2 \Big|_x^y}{t^2 \Big|_0^{90}} = \frac{(x + y)(y - x)}{8100}.$$

Since

$$y - x = 15$$

and

$$y = 15 + x,$$

we have

$$p = \frac{225 + 30x}{8100}.$$

Here we see that the probability increases linearly with  $x$ , the initial time of the period under discussion.

### GENERAL REFERENCES

Griffin, F. L., *Introduction to Mathematical Analysis*, Houghton Mifflin, Boston.

Uspensky, J. V., *Introduction to Mathematical Probability*, McGraw-Hill, New York, 1937.



# CHAPTER 46

## *PROBABILITY AND PROOF*

### **1. PROBABILITY IN CRIMINALISTICS**

In a criminal trial the aim of the prosecution is to prove the guilt of the defendant beyond a reasonable doubt. The term "reasonable doubt" has no precise definition. There has been little, if any, scientific approach to the elucidation of the word "reasonable." A great deal has been written concerning the validity and weight of certain kinds of testimony. The weight attached to eyewitness testimony, for example, is very great; in comparison, circumstantial evidence is held in low esteem. With the increasing use of modern scientific methods of investigation, it is expected that the importance of circumstantial evidence will be greatly enhanced. At present the defendant's fingerprints found at the scene of a crime are sometimes considered in themselves sufficient evidence to support a conviction, and this, simply because the probability of finding two identical fingerprints is quite small. The day should not be distant when a spectrographic analysis will be given the same weight in court as a fingerprint. That this condition does not exist at present is due, perhaps, to a failure to understand the common nature of these two types of physical evidence.

In a recent case of the authors, for example, the collision of an otherwise unidentified car with a newly painted bicycle was established by spectrographic analysis of the white paint which had been left on the car at the time of the collision. The analysis showed that all elements present in the paint on the bicycle were also present in the paint on the car. The significant aspect of the analysis was the presence of trace elements attributable to slight impurities which unavoidably distinguish one "batch" of paint from another and not merely one manufacturer's paint from that of another. The evidence here was of the same nature as that of the fingerprint. In the fingerprint the presence of a certain number of geometrical patterns of friction ridges establishes the print as unique, since in the experience of fingerprint experts there is only the remotest chance (the probability, almost, of a reversal of a law of nature) of the occurrence of a similar set of characteristics from an independent source. Similarly, in the spectrograph the presence of certain lines with varying densities describes a



pattern which in the opinion of an experienced spectroscopist may be unique, the unicity, to speak loosely, approaching that of the fingerprint in quality.

Many other examples can be given where physical evidence logically should possess the same forensic value as the fingerprint. A few are described below.

Glass fragments are found at the scene of a hit-and-run accident. Examination of a suspected vehicle reveals glass fragments of the remains of a headlight lens that fit a piece from the vehicle (in the manner of a jig-saw puzzle). Not only do the two curves of the glass fragments match, but the curves of the cross-sectional surfaces are also in agreement. The unique forms of these curves are practically impossible to reproduce intentionally in glass. To ascribe the correspondence to chance would be considered an affront to one's intelligence. The elements in this case which correspond to the characteristics of a fingerprint are the points of the curves when they are regarded as being plotted in some system of coordinates. Cases analogous to glass fractures are those involving torn documents, matches torn from match books, or broken automobile ornaments or accessories.

Tool impressions offer another familiar example. The edge of a tool such as a wood chisel is scarred in various ways. There is no predictable pattern to the notches which are made in the blade. When the chisel is used on a soft surface a trace of the edge is seen in a series of striations along the path of application (Fig. 76). A set of ten or twenty characteristics may be present in the impression to identify the tool. The spacing and depth of the nicks in the edge of the tool are the variables the values of which relate the tool to the mark.

Further examples may be given from the fields of handwriting comparisons and firearms identification. In all of these studies of physical evidence the nature of the problem of proof is the same: the discovery in the unknown of a number of characteristics which correspond to characteristics of the known. From the existence of these common characteristics the investigator concludes that the known and unknown possess a common origin because of the improbability of the independent occurrence of this set of characteristics. This improbability is presented to the court as one of the reasons for considering the defendant's guilt to be established beyond a "reasonable" doubt.

Throughout the description of these examples the concept of probability constantly appears. Although the fingerprint expert looks upon his conclusions as being based on common sense supported by experience, he is, nevertheless, groping toward the idea of probability. This reaching toward a scientific basis of reasoning is evident even in the early history of fingerprint classification. In 1892 Sir Francis Galton estimated the probability of two persons possessing the same fingerprint as  $1/(64 \times 10^9)$  (one chance in 64 followed by 9 zeros). Balthazard later put the probability at  $1/10^{60}$ .

The extension of the principles of mathematical probability to the frequency of occurrence of characteristics of physical evidence is not a simple matter. Assumptions that truly belong to the realm of the ideal are transferred to the world of reality. In the applications of the principles of probability which have been previously treated, the examples were confined to games of chance and



other ideal situations. The conditions of the problems considered were compatible with the assumptions implied in the definition of mathematical probability:

"If, consistent with conditions  $s$ , there are  $n$  exhaustive, mutually exclusive events, and equally likely cases, and  $m$  of them are favorable to an event  $A$ , then the mathematical probability of  $A$  is defined as the ratio  $m/n$ ."\*<sup>1</sup>

With what degree of assurance can we state in the case of a fingerprint that this (or that) precise number of characteristics represent  $n$  "exhaustive, mutually exclusive events"? The term "equally likely cases" offers even more formidable difficulties. The following criterion may be used. "Two contingent events are considered as equally likely if, after taking into consideration all relevant evidence, one of them cannot be expected in preference to the other."\*<sup>2</sup> How is this criterion to be applied, say, to the markings of a bullet in firearms identification?

To these questions there is no simple answer. It is not possible to give a numerical measure of the probability of an event unless we are given a set of alternatives which are equally probable. Our definition of "equally probable" involves the Principle of Indifference: "... if there is no *known* reason for predicating of our subject one rather than another of several alternatives, then relatively to such knowledge the assertions of each of these alternatives have an *equal* probability."†<sup>3</sup> The difficulties which this rule leads to, however, are quite formidable. It is necessary, in fact, to abandon any scheme of establishing *a priori* probabilities which would employ this rule.

If we limit ourselves to merely establishing upper or lower limits to the probabilities which we are seeking, we can greatly simplify the problem. The probability of an event such as those cited above may be established *a posteriori* as being within certain limits. The relative frequency of the occurrence of a characteristic, as shown by a great number of experiments, may be taken as an approximation to its probability.

Bernoulli's theorem is of particular relevance here: "With the probability approaching one or certainty as near as we please, we may expect that the relative frequency of an event  $E$  in a series of independent trials with constant probability  $p$  will differ from that probability by less than any given number  $\epsilon > 0$ , provided the number of trials is taken sufficiently large."\*<sup>4</sup>

Uspensky<sup>5</sup> cites a number of experiments which illustrate the theorem:

(a) Buffon tossing a coin 4040 times obtained 2048 heads and 1992 tails. The relative frequencies are

$$\frac{2048}{4040} = 0.507 \text{ for heads}$$

\* By permission from *Introduction to Mathematical Probability* by J. V. Uspensky, copyrighted 1937, by McGraw-Hill Book Company, Inc.

† By permission from *A Treatise on Probability* by J. M. Keynes, copyrighted 1921, Macmillan & Company.



and

$$\frac{1992}{4040} = 0.493 \text{ for tails.}$$

These frequencies are very close to the *a priori* probabilities of  $\frac{1}{2}$  or 0.500.

(b) In his *Grundzüge der mathematischen Statistik*, Charlier records that in 10,000 random drawings of a playing card from a full deck a black card was drawn 4933 times and a red card 5067. The relative frequencies are

$$\frac{4933}{10,000} = 0.4933 \text{ for a black card}$$

and

$$\frac{5067}{10,000} = 0.5067 \text{ for a red card.}$$

The theoretical probability for each is 0.5000.

(c) Bancroft H. Brown records the results of 9900 crap games. This game has been described in Chapter 45, where we saw that the probability of winning is

$$\frac{244}{495} = 0.493.$$

Brown obtained 4871 successes in his experiment. The relative frequency is

$$\frac{4871}{9900} = 0.491.$$

Other examples are cited by Keynes.<sup>6</sup>

From these experiments it is seen that relative frequency can be made to approach theoretical probability as closely as we please if a sufficient number of trials or cases is recorded. It is reasonable, then, to assume that the relative frequency determined from a sufficiently large number of experiments can be used in calculations in place of the theoretical probability in the problem which we are considering — the probability of occurrence of certain characteristics in samples of physical evidence. We must, however, restrict ourselves to estimates which lie within broad limits in order to avoid the many logical difficulties which are present.

This relative frequency must be determined by a statistical examination. In the case of fingerprints this is a comparatively simple matter since the number of recorded fingerprints is enormous. The circulation of records among police departments insures for the expert a sufficient amount of data for reliable estimates. The expert in other branches of police science, however, does not enjoy access to so large a mass of data. Usually he must rely upon his own experience. The handwriting expert, after the examination of thousands of cases acquires a fair knowledge of the frequency of occurrence of certain letter formations, and perhaps for certain characteristics can form some estimate of the probability involved.

The criminalistician, who must treat of other types of evidence such as spectrographic analyses or tire marks, is in a far less happy state. To understand his difficulties we must divide characteristics into two classes — group and



individual. For example, a group characteristic of a tire would be its manufacture; in a sample of paint it would be the ingredients. The individual characteristics are those which specify or identify a single sample of a substance or an object — the cuts and scars which the tire acquires in use — the trace elements in the paint, over the occurrences of which the manufacturer apparently is unconcerned — the unavoidable differences in density and refractive index which mark one pot of glass from a succeeding pot — the nicks found in the head of a hammer.

For the group characteristics it is possible to form a semiquantitative estimate of frequency of occurrence. One can ascertain the number of tires of a certain brand which have been sold in a certain area. The manufacturer's data will determine the number of cans of a certain paint which were available at a given time. The important characteristics, however, are those which are individual, and here the police scientist finds his professional life beset with difficulties. The frequency can no longer be determined by production-line figures. A large number of individual experiments is necessary. Is the scale count of hair sufficient to characterize the hair? Not unless thousands of experiments have been performed which establish the scale count as characteristic of a certain head and which indicate the frequency with which various scale counts occur. The frequency of occurrence of certain trace elements in paint can only be determined through a wide experience in spectrographic analysis.

The need for this type of data is keenly felt in police science. The data supplied by scientists in other professions are not entirely suited to the needs of the police laboratory. The peculiar problem of criminalistics is to detect the odd traces — the anomalies which are often of little interest to other sciences. The stray elements that creep into the production of certain metals are often of no importance to the manufacturers; nevertheless, they brand the metal for the criminalistician in a manner which is far more significant than the name of the manufacturer. The maker of a pair of rubber heels is interested mainly in elasticity, durability, and economy. The occurrence in the heels of cuts and other scars acquired through wear in no wise affects him. The forensic scientist, however, in comparing the heels with an impression would like to know the frequency with which he can expect this type of wear or this type of cut in the heel.

Research of this nature has not been neglected. Statistical studies have been undertaken in police laboratories in America, particularly in the West and Middle West. A good example of this work is a study of the physical properties of glass by Kirk.<sup>7</sup> In this experiment one hundred samples of glass were tested in order to determine the frequency with which the various values of the density and refractive index occur. The purpose of the study was to determine whether these properties alone are sufficient to identify a glass sample. It is to be hoped that research of this nature will be conducted on a more extensive scale in the future.

If we assume, now, that a statistical study has established for us the frequency with which certain characteristics occur in physical evidence, and if we further



assume that the frequency may be taken as an approximation to the probability of an event, how can the mathematics of probability assist us in the problem of proof? More specifically: Under what circumstances can we apply the law of compound probability? We restate this law as follows: The probability,  $P$ , of the simultaneous occurrence of independent events  $A_1, A_2, A_3, \dots, A_n$  is given by the product of their separate probabilities. Thus,

$$P = p_1 p_2 p_3 \dots p_n.$$

The naive application of this principle without regard to the individual nature of the problem will lead to many pitfalls. To quote Keynes:<sup>8</sup>

"Probability has become associated, therefore, in the minds of theorists with those problems in which we are presented with a number of exclusive and exhaustive alternatives of equal probability; and the principles which are readily applicable in such circumstances have been supposed, without much further enquiry, to possess general validity."

We apply this rule to a tool impression found in metal, such as that illustrated in Fig. 76. An examination of a test mark made with a suspected tool in similar metal reveals 15 scratches or lines which match 15 out of 19 of the striations of the impression received in evidence. If on examination of a number of similar tools we find that a line which will correspond to one of the lines in the impression is on the average on one of ten tools examined, we may assign a probability of  $\frac{1}{10}$  to each of these lines. Then the probability of finding 15 corresponding lines in another tool is given by (assuming each line an independent occurrence)

$$P = \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10},$$

or

$$P = \frac{1}{10^{15}}.$$

Hence, we can say that the probability of finding a tool other than the tool held in evidence to produce the impression is one out of 1,000,000,000,000,000 or  $10^{15}$ . Since  $10^{15}$  far exceeds the number of tools of this type existing in the world, we may say that we have proved beyond a reasonable doubt that *this* tool was used to make *this* impression.<sup>9</sup>

As another example let us consider a comparison of substance  $A$ , found on the shoe of a suspected burglar, with substance  $B$ , found on a window sill at the scene of the burglary. Spectrographic analysis reveals that the two substances are identical line for line in the spectrogram. The substances, then, are not only of the same nature but match also in regard to presence of a number of impurities. If we assign a probability of  $\frac{1}{500}$  for the discovery of a substance of that nature on the shoe of a person and a probability of  $\frac{1}{100}$  for the presence of each of four impurities which are found in the substance, we have for the compound probability

$$P = \frac{1}{500} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100},$$



or

$$P = \frac{1}{50,000,000,000} = \frac{1}{5 \times 10^{10}}.$$

In other words, the probability of finding the substance which was discovered on the shoe of the suspect in some place other than the window sill in question is one in fifty billion.

It should be noted that the reasoning in the latter example is not as satisfactory as that applied to the former. We shall return to this later. At present, the following additional examples are given to further illustrate the theory:

Osborn applies the rules of probability to a comparison of handwriting:

"The same problem may be stated in another way. We will say that movement or manner of writing will be represented by the fraction one-half; that is to say that all writers write in one of only two possible styles of movement, and let pen position, slant, shading, size, and alignment each be represented by the fraction one-half. The various letters, characters, abbreviations and pen marks in English writing are more than eighty in number, with scores of variations and modifications of each style which, when taken all together in the great variety of handwritings, are numbered by the thousand.

"We will assume that all characters except forty will be made exactly alike, and that those forty will each have but one possible modification of one kind in one direction instead of many as is the fact. We now have as representing our separate "events" forty-six fractions each of one-half, and the question to determine is how frequently will this group or any other particular selected group of varying forms and habits, all combine in another handwriting. Applying the Newcomb\* rule again, we find that even on this low basis the mathematical probability of two complete handwritings being identical is one in something more than sixty-eight trillions (68,000,000,000,000)." <sup>10†</sup>

Another example<sup>11</sup> from the work of Osborn is a case of a traced forgery in which thirty downward strokes of a signature were matched identically in the forged signature. Professor Benjamin Pierce of Harvard testified in part as follows:

"I have carefully examined the signatures of 1 and 10 of Sylvia Ann Howland. I have placed them over each other, and have compared their magnified photographs. The coincidence is extraordinary and of such a kind as irresistibly to suggest design, and especially the tracing of 10 over 1. There are small differences in every portion of the signatures, so that no letter of the one is precisely identical with that of the other; but the differences are such as to strengthen the argument for design suggested by the coincidences. . . . The mathematical discussion of this subject has never, to my knowledge, been proposed, but it is not difficult; and a numerical expression applicable to this problem, the correctness of which would be instantly recognized by all the mathematicians of the world, can be readily obtained. . . .

"The relative frequency of coincidence expresses how often there is a coincidence in either of the characteristic lines; such as in line 1 for example. The product of the relative frequency into itself expresses how the coincidence of a characteristic line 1 is

\* This is the law of compound probability, which for some reason Osborn associated with the name of Professor Simon Newcomb.

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combined with that of line 2; the cube of the relative frequency of coincidence shows how often there will be the simultaneous combination of the coincidences of the first three lines, and so on.

“‘Finally, the relative frequency must be multiplied into itself by as many times as there are characteristic lines to express how often there can be a complete coincidence in position of all the lines of the signature.

“‘In the case of Sylvia Howland therefore, this phenomenon could occur only once in the number of times expressed by thirtieth power of five (nine hundred and thirty-one quintillions of time — 931,000,000,000,000,000,000). This number far transcends human experience. So vast an improbability is practically an impossibility. Such evanescent shadows of probability cannot belong to actual life. They are unimaginably less than those least things which the law cares for.’”<sup>11\*</sup>

## 2. CONDITIONAL PROBABILITY

It was remarked above that some objection might be made to the rigor of the reasoning employed in the example of the spectrographic analysis. With the limited description of the analysis given there, the question might be raised: Should the presence of the impurities be considered as independent of the presence of the substance in question? Does not the probability of these impurities increase once we have granted the presence of the substance? We can clarify this problem somewhat by considering a simplified example:

A metal rod is found in the pocket of a suspected safe burglar. It is thought that the rod was used as a punch to knock in the dial of the safe. Particles of metal and paint are found on the rod. A spectrographic, qualitative comparison reveals that these substances are the same as the metal and paint of the safe. An inquiry of the manufacturers of the safe discloses that the selection of paint for a safe of this type is made from a group of four paints. We assume that from the analysis of the metal we can assign a probability of  $\frac{1}{1000}$  (neglecting trace elements for the present) to the finding of this particular metal, on the metal rod. The probability of finding a paint to match the paint of the safe is set at  $\frac{1}{500}$ . We assume also that there are no impurities in the paints. What is the probability of the simultaneous presence of these two substances on another metal rod?

If we were to naively apply the rule for independent events to this case we should have the result

$$P = \frac{1}{1000} \times \frac{1}{500} = \frac{1}{500,000}^{\dagger}.$$

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† If we were to include a consideration of impurities, the probability would be calculated as follows:

Using a conservative assumption, let us say that the metal punch had three common trace elements to which we may assign a probability of  $\frac{1}{10}$  for each; the paint of the dial had one common trace element (a probability of  $\frac{1}{10}$ ) and one uncommon trace element (a probability of  $\frac{1}{1000}$ ). The change in probability due to the impurities, then, is  $\frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{1000}$ . The total probability is now  $\frac{1}{500,000} \times \frac{1}{10^4}$  or  $\frac{1}{4} \times 10^{-12}$ .



To include cases of this nature in our theory of probability we must amplify the rule of compound probability with the following generalization. The probability of the simultaneous occurrence of two events  $A_1$  and  $A_2$  is given by the product of the unconditional probability of event  $A_1$  and the conditional probability of event  $A_2$  which assumes the occurrence of  $A_1$ .

The rule is readily extended to  $n$  events  $A_1 A_2 \cdots A_n$ .

The following example will illustrate the theorem for two events. A box contains seven balls — three red and four black. If two balls are selected at random from the box, what is the probability that they will both be black? Let  $p_b$  represent the probability of drawing a black ball and  $p_{bb}$  the conditional probability of drawing a second black ball.

$$p_b = \frac{4}{7}.$$

After the first black ball is drawn, only three remain. Thus

$$p_{bb} = \frac{3}{6}.$$

Hence the probability  $P$  of drawing two black balls is, from the theorem,

$$P = p_b \times p_{bb}$$

$$P = \frac{4}{7} \times \frac{1}{2} = \frac{2}{7}.$$

This concept of the conditional probability of certain of the events must be taken into consideration whenever the principle of compound probability is applied. It is for this reason that one must be hesitant to loosely apply the principles of probability to cases in which some of the characteristics are associated with one another and hence may no longer be considered independent events. In handwriting comparisons, for example, the footing may become exceedingly treacherous for the expert who does not recognize the associations of characteristics. A novice will be inclined to designate as "independent events" two letter formations such as  $h$  and  $l$ ; whereas in fact they may be associated characteristics, because the writer is adhering to the rules of a specific school of penmanship — the Spencerian school, let us say, or the Palmer Method. If the  $h$  possesses a peculiar formation we should expect the penman, if he is conscientious and not particularly imaginative, to form his  $l$  in similar fashion. Thus the probability of the  $l$  is conditioned by the occurrence of an  $h$  of the same school of penmanship; and, if we are to assign a probability of  $\frac{1}{8}$  to the  $h$  we may not assign an equal probability to the  $l$  but must set it at some lower figure, say  $\frac{1}{9}$ . Similarly, a handwriting expert must be wary in assigning separate probabilities to the slant of individual letters where the slant should properly be considered a characteristic of the penman's writing in general. These, however, are precautions which the expert instinctively takes without necessarily being articulate in the matter of the probabilities involved.

Since there are pitfalls to be encountered by the ill-advised use of the principles of probability, the testifying expert should be extremely conservative in his semiquantitative estimates of the probability of the occurrence of characteristics of physical evidence. The important element is the application of the



principle of compound probability; namely, the fact that the probability increases exponentially with the number of characteristics. If he is able to make this point clear, the full weight of his testimony will be realized.

### 3. THE GENERAL APPLICATION OF PROBABILITY IN COURT TESTIMONY

The principles which we have discussed above should not necessarily be confined to circumstantial evidence. They may with discretion be applied to all the facts which are adduced to prove the guilt or innocence of the defendant.

The presentation of evidence in a criminal trial, usually involves a set of events or circumstances connecting the defendant to the crime with various degrees of probability; for example, the defendant's proximity to the scene of the crime; his hat found on a chair; the victim's wallet found in his possession; etc. None of these facts, taken separately, may be conclusive evidence of guilt. When, however, the whole series of facts is considered, the case against the defendant appears more convincing. The district attorney in summing up such a case usually speaks of the "chain of evidence" and the "overwhelming weight of circumstances." Underlying the various locutions which he employs is the fundamental concept of compound probability.

The great difficulty in applying this rule to the data of evidence lies in the fact that it is a mathematical concept and, as such, to lawyers and jurors appears to be esoteric, in spite of its essential simplicity. The assignment of numerical values to the probabilities of separate *events* will elicit no objection from the layman. He will readily concede that these values may err on the side of conservatism. Nevertheless, he will resist accepting the conclusion (i.e., the probability resulting from the product) which follows logically from the fundamental laws of probability.

Another reason for this reluctance, perhaps, is the unfortunate connotation of the word *probability*. An astute counsel will play upon the word *probability* to the confusion of the jurors. He may, for example, state that although the conclusion is claimed by the prosecution to be highly probable, it is still only "probable," as who should say, "It will probably rain tomorrow." The technical concept of probability is difficult to comprehend by a person who has consistently employed the term in the precisely opposite sense.

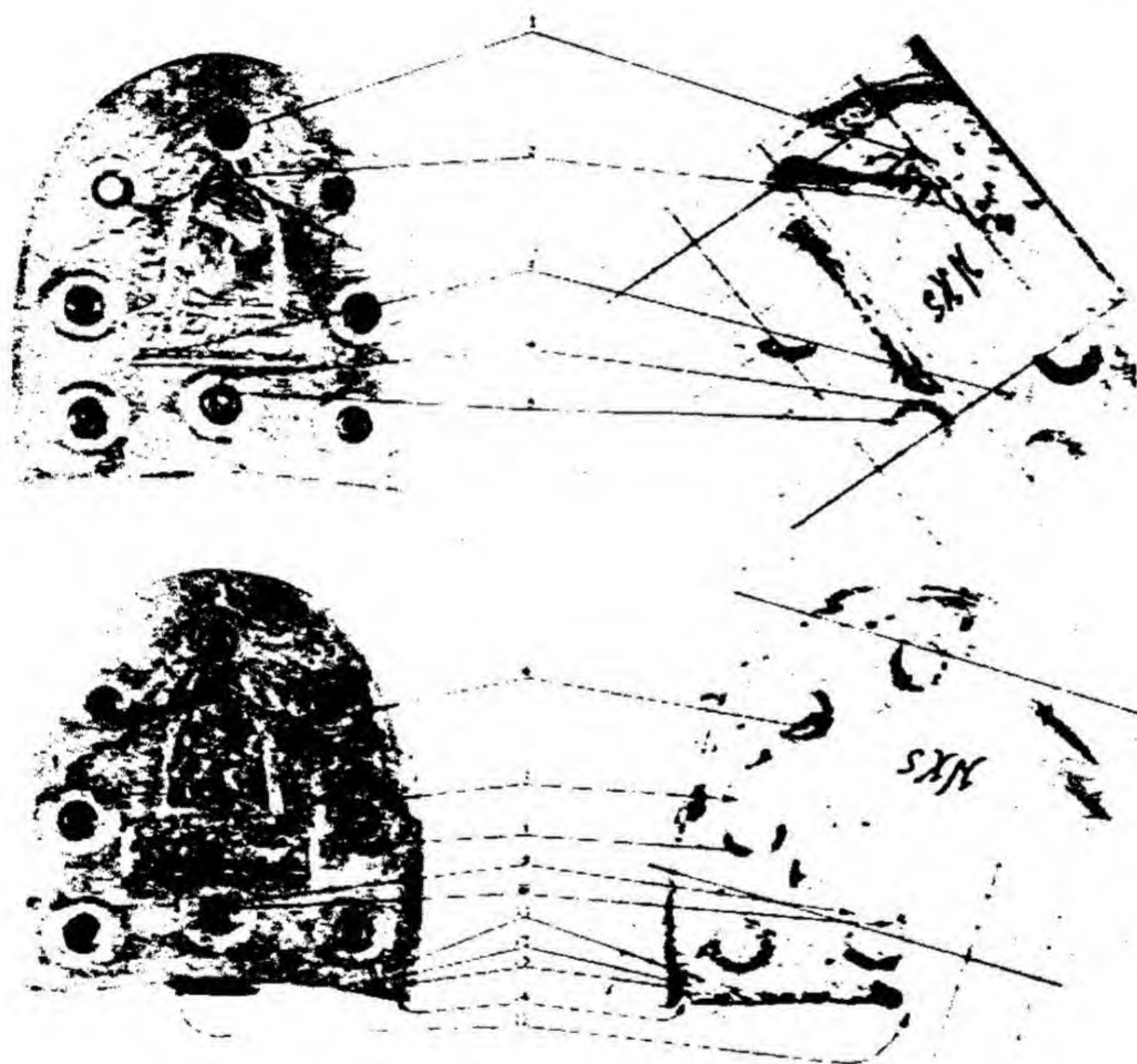
To these difficulties there appears no ready solution. They are part of the general problem of the weighing of scientific evidence. As long as scientific evidence is evaluated and interpreted by lawyers and jurors who are scientific laymen, the problem will remain. The difficulty can to some extent be resolved by the ability of the expert to present the principles on which his findings are based in simple terms without any specious air of profundity or verbal reliance on magical "rules."

Examples of the application of the ideas of mathematical probability are given below. Serious objection can, perhaps, be taken to some of the statements on the grounds previously described. The chief value of these cases, however, is



the illustration of the general principle which should guide the evaluation of evidence in a scientific manner.

*EXAMPLE 1.* In the commission of a safe burglary, the criminal scattered a number of papers on the floor. On one of these papers a right and left heel print were found. A suspect was "picked up" two blocks away from the scene of the crime. On examining his heels a number of points of correspondence were found between his heels and the marks on the paper. Figure 314 is a photograph showing the correspondence between the heels and the prints. Some of the points indicated in the illustration merely establish that both heels are made by the same manufacturer. The other points of correspondence are defects in the heels due to wear, which show themselves in the prints. It is with these



**Fig. 314. A comparison between heel marks found at the scene of a burglary and the heels of a suspect.**

latter defects, the small nicks or gouges in the rubber, that we are concerned. Erring on the side of generosity (to the defendant) we shall assign arbitrarily a value of  $\frac{1}{10}$  to the probability that a rubber heel should bear any one of these nicks in the exactly corresponding position where it is found on the heel in question. Considering, now, each of the defects or nicks as an independent event, and assuming that ten such defects are discovered, we find on applying the law for independent events that the probability of finding a pair of heels with precisely these defects is  $(\frac{1}{10})^{10}$  or  $10^{-10}$ . In other words we should expect to find only one such pair of heels if we were to examine ten billion pairs; or, again, the odds are ten billion to one against finding another pair of heels which will make prints to correspond to the prints found at the scene of the crime.

It should be remembered that the errors in this calculation favor the defendant. Certain other factors which would make the probability of his inno-



cence smaller have been neglected — for example, the coincidence of his being in the neighborhood at the time of the commission of the burglary.

The underlying difficulty in these estimates is the assignment of a numerical value to the probability of any given circumstance or event. What numerical value, for example, should be assigned to the probability of the defendant's being in the neighborhood at the time? Even in the simpler matters, such as the defects in the heels, an objection will be raised. In these cases, however, a sound basis for the numerical value can be established by a statistical analysis. It is possible to examine several hundred heels (by visiting shoe repairing shops) and note the frequency of occurrence of scars in certain areas.

*EXAMPLE 2.* In the commission of a burglary in a certain store, the glass of the door window is broken by the criminal while making a hurried exit. In a street adjacent to that of the store a patrolman seizes a running man. On examination at the station house it is found that the man is bleeding from a cut at the knee. His trousers are torn in the corresponding area. In the cuffs of the trousers and in a pocket of his jacket particles of glass are found. The capture of the suspect occurred at 3:40 A. M., a few minutes after the breaking of the glass. At the laboratory the glass discovered in the clothes is found to have the same physical properties as the glass from the broken door. Paint found on the glass particles is shown to be of the same composition as the paint on the door glass. Form an estimate of the probability of the suspect's innocence of any connection with the breaking of the door window of the store.

We shall base our estimate on the following points:

- (a) Probability of a glass sample, selected at random, being identical with the glass of the door in chemical and physical properties:  $\frac{1}{1,000,000}$
- (b) Same as (a) for paint found on glass:  $\frac{1}{1,000,000}$

The product of these probabilities is  $10^{-12}$ ; hence the probability of finding another such specimen of painted glass is one chance in a trillion. The following additional circumstances would further strengthen the argument although we assign no quantitative value to the probabilities:

- (c) Probability of suspect's being in that area at that time (his habits, and the address of his home are taken into consideration)
- (d) Probability of suspect's being found running at three o'clock in the morning (his reasons are taken into consideration)
- (e) Probability of suspect's suffering a bleeding knee
- (f) Probability of suspect's trousers being cut at the knee. [This circumstance is independent of (c) in the sense that a laceration of the knee is ordinarily not accompanied by a cut in the clothing.]
- (g) Probability of finding glass particles in trouser cuffs
- (h) Probability of finding glass particles in pocket of jacket

The aim in both of these examples has been to demonstrate that the probability of the innocence of the suspects is so small as to justify the jury in finding them guilty beyond a reasonable doubt. In both cases extremely small values



were derived for the probability of innocence. From a consideration of these numerical estimates there naturally arises the question of the approximate value which must be reached in order for us to say that the probability arrived at by the evidence removes the defendant's guilt from the domain of reasonable doubt.

This question is not readily answered. Offhand, one might say that the probability is sufficient when the denominator of the fraction which is used to express it exceeds the population of the world; that is to say, a probability of  $1/(3 \times 10^9)$ . Less conservative values are given in other texts. Where the problem is simply that of identifying a tool mark or a substance containing trace elements smaller values will serve to establish the identity. Souder<sup>12</sup> discusses this problem in an analysis of a hypothetical case involving two typewritten documents, in which five of the letter characters represent *departures from the normal*. After assigning values to the probabilities to these characteristics, Souder estimates the final probability.

"... If these evaluations are proper we have only to multiply  $\frac{1}{20} \times \frac{1}{50} \times \frac{1}{40} \times \frac{1}{100} \times \frac{1}{10}$  to determine the probability of our finding a second typewriter which will show all the defects of the first. The answer is  $\frac{1}{40,000,000}$ .

"Interpreted, this means that we would not expect to find two typewriters which will produce similar documents until we searched a lot of 40,000,000. Since our initial assumption admitted only 1,000,000 such machines in existence, we find our conclusion, that both documents were written on the same machine (though not absolute), established beyond a mathematical doubt. To me this expression 'beyond a mathematical doubt' transcends the expression 'beyond a reasonable doubt' in that it is capable of detailed analysis and when so analyzed is perfectly understood by all.

"Suppose the report does not establish such an extremely remote possibility of recurrence. Suppose the final fraction for recurrence of the typed characteristics had come out only  $\frac{1}{100}$ . Is such a report of value? Yes, if the number of typewriters upon which the document would have been written can be limited to 100 or less, the report is vital. Similarly, in handwriting we do not have to push the test until we get a fraction represented by unity divided by the population of the world. Obviously the denominator can always be reduced to those who can write and further to those having the capacity to produce the work in question. In a special case it may be possible to prove that one of three individuals must have produced the document. Our report though it shows a mathematical probability of only one in one hundred, would then irresistibly establish the conclusion."<sup>12\*</sup>

The problem of applying the theories of probability to court testimony has been treated in the past by a number of famous mathematicians and logicians.<sup>13, 14, 15, 16, 17, 18, 19</sup> Although their conclusions are, in the main, questioned by modern logicians, their work should, nevertheless, be studied by those who wish to apply a scientific method to the evaluation of evidence. The questions which have been raised in this chapter will, perhaps, be ultimately answered as our knowledge of the logical foundations of probability is further developed. Remarkably few treatises have been written on this latter subject. Within the

\* W. Souder, "The Merits of Scientific Evidence," *J. Crim. Law and Crim.*, 25, 683-685 (1934).



last eighty years the only systematic works in the English language have been those of Venn and Keynes. Modern statements<sup>20, 21, 22</sup> relating to the evidentiary value of physical evidence have been mainly qualitative in nature in the sense that they have avoided any estimate of the relative values of the various types of clue materials and of the conclusions which may be logically reached by considering their cumulative effect in the light of theory of probability.

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# *CHAPTER 47*

## *SOME MISCARRIAGES OF JUSTICE ANALYZED IN THE LIGHT OF CRIMINALISTICS*

Perhaps the most satisfactory method of demonstrating the unique service which criminalistics and the concept of probability offer to judiciary proceedings is to consider some cases in which the present trial system was found inadequate by permitting miscarriages of justice. There are several studies<sup>1-6</sup> which can be used to supply examples of mistakes in administration of justice that might have been prevented, had the concept of criminalistic probability been suggested to the jury as a criterion that would be helpful to them in their deliberations concerning the innocence or guilt of a defendant on trial. It is not possible to examine each case in detail; hence the following diagnosis of the protection afforded the innocent by the science of criminalistics must, for the most part, be generalized. Some of the main reasons for the conviction of innocent individuals appear to be:

- Mistaken identification
- Inadequate circumstantial evidence
- Framed and simulated evidence
- Perjury
- Unreliable "expert" testimony
- Overlooking and suppressing evidence
- Excessive zeal on the part of investigators and prosecutors

### **1. MISTAKEN IDENTIFICATION**

There are many studies which verify that testimony based on visual and other sensory experiences is frequently quite unreliable.<sup>7-14</sup> As a matter of fact it is a well-established principle of applied psychology that there are individual differences in capacity to give accurate testimony of this kind, since errors owing to differences in perception and attention at the time of an unexpected event and later lapses in memory and susceptibility to suggestion during interrogation



may cause variations from the truth. Consequently, sensory evidence is not considered in criminalistic probability. If some procedure embodying the suggestions of Wigmore,<sup>15</sup> Munsterberg,<sup>16</sup> Burtt,<sup>17</sup> and Poffenberger,<sup>18</sup> relative to possible improvements in evaluating sensory evidence is ultimately adopted, it might become possible to consider this type of testimony in criminalistic probability calculations.

In certain situations, the laboratory may be able to verify whether it is possible to make the observations described by a witness. Thus Hirschberg<sup>19</sup> cites a case in which expert testimony concerning the visibility on a late December afternoon in Bavaria showed that the testimony of two witnesses who claimed to have identified a man at a distance of 310 yards was in error since this was impossible under the conditions.

## 2. INADEQUATE CIRCUMSTANTIAL EVIDENCE

As we have seen in the previous chapter, circumstantial evidence is a valid and effective form of proof when it is subjected to correct interpretation. Unfortunately, however, the term has so often been used in deprecating context that jurors are inclined to shy away from the true meaning of the evidence when they are told that it is "purely circumstantial." The disrepute in which such evidence is sometimes held is attributable to those case histories wherein the circumstantial evidence was insufficient to warrant the conclusions which were made. It was not that the nature of the evidence was at fault, but rather that the "amount" of evidence was insufficient. Thus it will frequently be found in such cases that the facts were incorrectly interpreted by attaching greater significance to them than was warranted. Here again, a scientific statement of the significance of the evidence would have clearly shown its inadequacy.

As an example of an erroneous conviction based on inadequate circumstantial evidence alone, let us consider the Lyons case.<sup>20</sup> The facts upon which the jury based their conviction are listed briefly below:

### Facts

- (a) Two men, *L* and *S*, were known to have had a quarrel, and *L* threatened to kill *S*.
- (b) *S* disappeared completely, offering or leaving no explanation for his departure.
- (c) A short time later a body was found in a river nearby.
- (d) This body was disintegrated beyond recognition but was similar in build and size to *S*.
- (e) Various articles of clothing found on the body were identified as being similar to those worn by *S* when last seen.
- (f) After the body was buried, a friend of *S* (who had not seen the corpse) described a cheap metal ring with a setting of purple glass which was worn by *S* on his little finger of the left hand. The corpse, upon being exhumed, was found to have on the same finger a ring that fitted the description given.



Considering this set of circumstances we find that incidents (a) and (b), while suggesting *L* as a suspect are of too frequent occurrence to be of great value. Facts (d), (e), and (f) are the most important points in the case. Do they establish a *corpus delicti*? Is the body that of *S*? Facts (d) and (e) are not particularly helpful here, since the body and clothes have been in the water for some time. The weight of (f) depends first on an accurate identification of the type of ring, and second, on a knowledge of the prevalence of rings of this type. In the absence of this information fact (f) cannot be given a high probability value. Thus on the basis of facts (d), (e), and (f) the identity of the body has not been established sufficiently to base an unequivocal identification of it as being that of *S*. If this case were to occur today, modern autopsy procedures coupled with available dental or other clinical records, would most likely have been more effective in establishing the identity of the body.

Another case in which a set of circumstances apparently points strongly to the guilt of a suspect in a homicide case is described by Radin.<sup>21</sup> It appears that the suspect was apprehended because he aroused the suspicions of some detectives by acting in a manner similar to that probably used by the criminal. He never denied the murder, choosing to remain silent instead; his alibi concerning his whereabouts on the night of the crime was found to be a lie, and further investigation disclosed that he was in the vicinity at the time the crime was committed; stains on his clothing which he attributed to wine were found to be human blood; and pieces of ragweed similar to those found in his trouser cuffs were also found at the scene of the crime. While these facts seem formidable, if the evidence is considered in the light of criminalistics, it will be seen that the probability value of the physical evidence in the case was not sufficient to justify a conviction. Furthermore the unusual conduct of the suspect, i.e., his lack of denial of the killing and his specious alibi, are mitigated by the fact that his foreign background made him wary of police methods so that through distrust or fear he hesitated to cooperate in the investigation. The innocence of this suspect was later proved by the arrest of the real killer who admitted his guilt.

An actual example in which criminalistics afforded protection to an innocent man who appeared guilty because of a set of circumstances is cited by Hoover.<sup>22</sup> In this case a scientific examination of blood stains found on a suspect's clothing sustained his contention that they were of animal and not of human origin. Again, the physical evidence would have been insufficient grounds upon which to base a conviction, but was more than sufficient for establishing that the outward appearance of the circumstances was quite misleading.

While the physical evidence in a case may be inadequate, it sometimes may be combined advantageously with the methods of applied psychology to induce a suspect to make a confession. An actual case is described by Radin<sup>23</sup> in which the physical evidence, although by itself insufficient for a conviction, was employed at the psychologically propitious moment. After a series of interviews with a suspect in which he was instructed in the theory of blood grouping and informed of the results of grouping tests made on evidence found in his room



and near the deceased's body, the suspect was finally induced to confess to a homicide.

### 3. FRAMED AND SIMULATED EVIDENCE

Some cases in which persons are wrongly convicted involve situations where physical evidence has been left or "planted" at the scene of a crime. This is done by the real criminal to divert suspicion from himself by incriminating an innocent person. If this were cleverly managed, using a sufficient variety of clue materials, it is quite possible that criminalistic probability would offer no greater protection to the innocent than the present methods. However, the laboratory will in the majority of these cases be able to detect the simulated evidence. The reasons for this are simple. The criminal is frequently suffering an emotional disturbance while committing the crime and while substituting the fraudulent clue materials. This in addition to the fact that he usually has little, if any, experience in the appearance or requisites of physical evidence, enables the deception to be uncovered. For example, Phillips<sup>24</sup> cites a case in which a corpse was found with a thick lock of hair grasped in one hand. This hair was found "to match exactly" hair of a suspect. On the basis of this and other "planted" evidence the suspect was found guilty. Later the true culprit confessed his guilt. He explained that he had been able to obtain enough hair from the comb of the innocent suspect to make a "tolerably stout lock" which he placed in the hand of the corpse. Today, however, this hair would have been more carefully examined and from an inspection of the root ends it would have been determined whether the hair had or had not been pulled out by force. Armed with this evidence of simulation, closer scrutiny of the other facts in this case would, very likely, have resulted in saving an innocent man from the unjust punishment which he suffered.

The Perry-Palm Case<sup>25</sup> is an actual example of the value of a scientific examination of evidentiary traces left at the scene with the intention of framing an innocent party. Not only was the scheme frustrated by the work of the laboratory, but the real murderer was identified and subsequently convicted.

Another somewhat common method employed by those who wish to "frame" an individual is to start ugly rumors about the fate of a person who has disappeared recently and who is, in some manner, connected with the intended victim. In most cases this disappearance is induced by the "framer" through blackmail, fear, or conspiracy. When community interest and anger are at their height the "framer" arranges for a dead body, usually mutilated, to be discovered under suspicious circumstances. Almost inevitably this body is taken to be that of the missing person and the framer's intended victim is now charged with the crime. This method, no doubt, was often successful before the techniques of the medical examiner were developed. Today, however, this branch of criminalistics serves as a bulwark against such misdeeds. The celebrated Ruxton Case<sup>26</sup> is an outstanding example of the resourcefulness of the medical examiner in the reconstruction of mutilated bodies.



#### 4. PERJURY

Associated with each of the other reasons for the conviction of innocent persons is the possibility of willfully perjured testimony. While scientific criminology affords protection if it concerns physical evidence, the perjured testimony is generally given with respect to alleged visual observations. Under these circumstances protection of the innocent depends upon the use of applied psychology and the administration of tests for deception<sup>27,28,29</sup> by the authorities concerned during the investigative phase of the case.

Reik<sup>30</sup> discusses a case of an erroneous conviction based on an admixture of perjury, circumstantial evidence, and mass psychology. After studying the alleged facts in the case, the usefulness of giving tests for deception to all witnesses and suspects is very apparent. Such tests, competently conducted, undoubtedly would have ferreted out the real murderer, who confessed his crime a few years later because he had become conscience stricken.

#### 5. OTHER REASONS

The other reasons given at the beginning of this chapter need not be discussed. It must be assumed that an expert is honest, conscientious, and assiduous. Since his ability to continue as an expert witness in court depends upon his having a good reputation, it is not likely that he will jeopardize his position by overlooking or suppressing evidence, by submitting unsupported findings solely to satisfy the demands of an overzealous prosecutor or by attempting to offer testimony about technical matters in which he is not an expert.

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# CHAPTER 48

## LOOKING AHEAD

Evidence in criminal investigations may be divided into two broad categories: informational and physical. Informational evidence is obtained from the observations of eye-witnesses, interrogation of suspects, confessions, "tips," and so forth; physical evidence has been discussed in the preceding chapters of this work. Crime investigations have traditionally relied upon information evidence as *the* means of solving a crime. The Wickersham Commission<sup>1</sup> and Hopkins,<sup>2</sup> however, have focused attention on the many abuses which can result when police officers or other law enforcement officials in their zeal to accomplish results attempt to obtain informational evidence by resorting to methods that have been described aptly as the "lawless enforcement of the law." Other critical studies,<sup>3,4</sup> in which measures have been suggested for improving police administration, have been published. Unfortunately at the time of their preparation it was still a little too early to see clearly the function that a police laboratory would have in improving these conditions. The development of facilities for the examination of physical evidence was accordingly not guided by a progressive viewpoint, with the result that police administrators, in many cases without the proper scientific background, were given the task of organizing the police laboratory. Needless to say, the results often left much to be desired. Smith,<sup>5</sup> in viewing the rapid progress made in a decade or so, apparently believes that police science is now more or less well established. Not being a physical scientist, however, it would be difficult for him to perceive that criminalistics is as yet a relatively unorganized area of knowledge. With few exceptions, little if anything worthy of the name *research* is being carried out consistently as part of an integrated program designed to supply information necessary for more effective examination and evaluation of physical evidence. Men qualified by education and experience to be "experts" in blood grouping are not permitted by trial judges (and, in certain states, by state law) to testify because they have not M.D. degrees. As Boyd<sup>6</sup> points out, there is nothing particularly medical about blood grouping, and the average medical doctor is not qualified to carry out forensic blood grouping tests; while a great many of non-medical scientists are so qualified. On the other hand, *questioned document examiners* are welcomed in court and are permitted to express their opinions in disputed handwriting



cases even though they have had no academic scientific training or any formal course in the subject or in allied subjects and auxiliary disciplines.

The present position of criminalistics among the sciences may properly be compared with that of chemistry in the nineteenth century: it is the fortuitous result of isolated, individual effort and not the planned march of organized endeavors. No doubt this unhappy condition is largely attributable to the predominating influence of the "practical" mind as distinguished from the scientific spirit. At present the fostering of pure research is a concept foreign to many authorities controlling police policies. Their interest lies in *this* particular case and *that* specific bit of physical evidence, not in the elaboration of a general theory, however fruitful such an investigation may be twenty years hence. For example, some departments will harbor the unschooled document examiner whose scientific equipment consists of little more than a few specifics. They will not, however, contribute to the financing of a research project which will investigate the chemistry of inks and papers with a view to providing a general approach to document problems. Their position is analogous to that of the city dweller who, since he purchases his vegetables at the corner grocery, can see no cogent reason for his contributing by way of taxes to agricultural experiments.

This reluctance to sponsor research does not arise from the peculiar character of police organizations. It is, rather, an aspect of civil governing bodies in general and, as such, is indicative of the temper of the public. A large mass of people is still unaware of the fact that research is profitable -- that it is for the precise reason of profit that many commercial concerns have established research units.<sup>7</sup> This condition of public indifference undoubtedly suffered a profound shock at the revelation of the atomic bomb. The government had subsidized scientific research, and science had declared a dividend out of all proportion to the investment. Radar and the proximity fuse are other examples of the ability of organized scientific groups to solve specific problems under government sponsorship. Concerted research is now almost the rule in medicine and industry. Synthetic rubber, antimalarials, antibiotics, television, and nylon are only a few of the many important developments which required hundreds of specialists, working together, to bring a laboratory idea to fruition for practical purposes.

These accomplishments of science have assisted greatly in awakening the public to its responsibility in fostering research on a broad scale. The near future should see the establishment of many research programs in which various problems of science will be attacked by a large number of workers specifically assigned to the tasks. If the urgency of the need for research in the field of criminalistics can be sufficiently publicized, a program of this nature will no doubt be instituted in police science.

## **1. THE NEED FOR AN INSTITUTE FOR THE STUDY OF CRIMINALISTICS**

In order to remedy these conditions, it would be necessary to establish an organization or institute that would perform the following services for the police



departments, judges, lawyers, and others interested in the improvement of criminal investigation and criminal justice. Many members of the legal profession are aware of the desirability of having some means, whether it be a "Ministry of Justice,"<sup>8</sup> a "National Scientific Commission"<sup>9</sup> or an "Institute" (such as is suggested here) through which the problems to be described can be resolved.

The remaining sections of this chapter are devoted to a consideration of the necessity for an integrated research program; several research projects are mentioned, and the results to be expected are indicated.

### Qualifying Experts

Some attempts have been made to indicate for a particular field what qualifications of education or experience are required before an individual may be considered an expert.<sup>10, 11, 12</sup> What is needed, however, is a general approach to the problem, and not isolated attempts in one or two branches of criminalistics. Certainly, trial judges would be greatly assisted if some recognized group undertook to certify that by their standards or tests an individual may be shown to be qualified to perform certain physical, chemical, or other tests on evidence for forensic purposes. The procedure described by Morgan<sup>13</sup> governing expert and opinion evidence would also be applicable, except that through an "Institute" the views of several top-flight men covering the various areas of scientific knowledge would be available to guide the trial judge and other parties interested in learning the requisite qualifications of an expert in a particular field.

### Advanced Studies

Within the past few years a trend has developed in science to have various leaders in their fields prepare a compendious treatment of their specialties, describing the principles, instruments, and applicability to other branches of knowledge. For example, Glasser<sup>14</sup> has edited a book in physics for medical students; Weissberger<sup>15</sup> has edited a book in physical chemistry for organic chemists. Each chapter in these books was prepared by one of the leaders in that phase of the work. As a branch of science becomes broader in scope or increases in complexity, the necessity for this approach to textbook writing becomes more desirable. In a field as diversified as criminalistics, it is a necessity if the work is to be treated on the graduate level. On a limited scale, Shore,<sup>16</sup> Snyder,<sup>17</sup> and others<sup>18</sup> have written texts covering certain aspects of criminal investigation in which they had such contributors as C. A. Mitchell, C. W. Muehlberger, C. M. Wilson, H. Mulbar, D. G. Monroe, R. F. Borkenstein, and others contribute chapters on their specialties.

The Institute, then, could engage various leaders in those branches of learning that are applicable to the work of criminalistics to prepare monographs or chapters for a book similar to those mentioned above.



### **Standardized Procedures**

The Association of Official Agricultural Chemists, The American Society for Testing Materials, and many other organizations or industrial groups have established official methods of analysis for various substances which they are required to analyze or inspect. As a result of the work of these groups authoritative, competent, and unbiased methods of wide applicability have been developed. Courts, in proceedings where different methods of analysis have been employed and where it becomes necessary to make a choice, usually will recognize the official methods advocated by scientific societies.

The advantages of having standardized procedures and official methods of analysis for examination of evidence in criminal investigations would be similar. Unlike ordinary analytical laboratories, however, the police laboratory has little control over the evidence sample submitted for analysis. For this reason, then, it is not possible to specify exactly how the analysis is to be performed in *all* cases. In these situations the practice now followed of having the analyst choose or develop his own method would continue. He, of course, should be able to explain why he thought it wise, or found it necessary, to depart from the standardized procedure (if such exists).

### **Internal "Branding" of Clue Materials**

A recurring problem of the police laboratory is the detection of the source of a particular sample of clue material. Where the sample is small the police scientist employs spectrographic methods of analysis. The value of this analysis depends upon the presence of trace elements which uniquely identify the substance. Trace elements, however, are not always present in sufficient numbers for the spectroscopist to be specific in indicating the source. A practical measure for aiding the police in their work would be the addition by the manufacturer of unusual trace elements. Thus bullets could be distinguished according to manufacturer and year of production by the addition of a specified trace element in specific amounts to the metal. This internal "branding" could be readily applied to inks, paints, glass, lipsticks, and many other products. In the case of ink the trace elements would serve to identify the year of manufacture of the ink and thus help to frustrate the future forger.

In order to enlist the cooperation of industry on a nationwide scale, a complete plan, developed through research, would have to be presented to the manufacturers. The selection of trace elements for particular products would be determined by the Institute in conjunction with the manufacturer. In this way tracers could be selected which are not harmful to the user and which do not affect the appearance or quality of the product.

### **Financial Support**

In order to accomplish these objectives such an Institute would require financial support. This may perhaps be obtained by grants from foundations, endowment funds, private gifts, and appropriations of public funds (municipal,



state, and federal). Fosdick,<sup>19</sup> in cautioning that police departments are graveyards of projects and improvements which, if they had been permitted to develop to maturity would have reconstituted police work, indicates that it is desirable to have financial support outside of governmental appropriations in order to insure continuation of the work, since progressive programs require a number of years to accomplish, and must therefore not be dependent upon the political fortunes of any particular administration.

## 2. RESEARCH IN CRIMINALISTICS

Research topics in police science may be grouped into three categories: fundamental research, instrumentation, and collection of statistical data. An impressive list of problems can be readily drawn up under these classifications. Of these a few will be stated below for purposes of illustration.

### Fundamental Research

While in general, physical and chemical theory is advanced far beyond the requirements of the police laboratory, occasionally it appears to be inadequate in explaining certain phenomena which have been found experimentally to be useful. For example, chloral hydrate (Chap. 37) has been successfully used to develop the writing on charred documents. The reasons for the efficacy of this method are not apparent. However, if a theoretical interpretation of the nature of the reaction were possible, it would also be fruitful in suggesting other lines of approach, such as use of related compounds or optimal experimental conditions.

Another example of a subject which has been inadequately understood is the use of iodine for such purposes as latent fingerprint development, secret writings, indented writings, and erasures. Formerly the term *selective absorption* was used to explain the action of iodine in these applications. Rowe,<sup>20</sup> however, as a result of an investigation of the staining of fibers by iodine, has developed a theory which elucidates more satisfactorily the nature of the chemistry involved. According to Rowe, the absorption of iodine is a colloidal phenomenon which is influenced by any condition that changes the nature of the absorbed iodine, i.e., particle size, or the nature of the absorbent, e.g., hydration. Accordingly, the role of potassium iodide appears to be mainly one of formation of a complex ion with the iodine; whereas the salts (zinc chloride, aluminum chloride, and calcium chloride) are employed to swell the fibers and to increase the size of the iodine-iodide water absorption complex. The use of these salts therefore increases the amount of iodine absorbed on the fiber.

From this theory the criminalistician can readily see that the result obtained by fuming a paper with iodine will not be quite the same as that obtained by using an iodine solution such as that described on p. 504. Thus, if its use does not preclude further examination and it is otherwise permissible, a solution of iodine is to be preferred to iodine fuming since, in the case of the solution, a greater amount of iodine enters into the reaction.



The nature of the chemistry of the precipitin and agglutination reactions of blood presents a problem the solution of which may be of great value in criminalistics. An insight into this subject would perhaps lead to the development of a simple, specific field test for human blood stains.

The methods of developing latent fingerprints at the scene of a crime are not entirely satisfactory. Too little is known of the limitations placed upon the various methods by the different surfaces on which the print may be found. At present considerable mysticism and superstition influence the selection of fingerprint powders. Little is known of the physics and chemistry which determine the composition of a powder of good adherent qualities. The effects of granulation, density, and possible reactions with exudations of fingers must all be investigated more thoroughly. Many other similar problems could be mentioned here. Even this brief list, however, should offer an appreciation of the great advances that could be made if this type of knowledge were available to police laboratory workers.

### **Instrumentation**

In Chapters 42, 43, and 44 a few instruments were discussed which hitherto have been more or less neglected in their application in criminalistics. In addition to increased employment of these instruments along the lines indicated, there is needed further research into other possible applications. For example, in the chapter on semen examinations, it was pointed out that the only diagnostic test is the microscopic identification of a spermatozoon. It need hardly be mentioned that all too frequently this result is not achieved even under the promising condition of having a stain that appears to possess all the superficial characteristics of a seminal stain. Thus it would be desirable to have a chemical or physical method which would identify human seminal fluid. In this connection, spectrophotometric and x-ray diffraction studies of processed seminal stains might be found useful.

Other instruments or techniques, which have not been mentioned previously but which appear to be useful in police laboratory work, include the polarograph, electron diffraction, mass spectrograph, gas analysis by thermal conductivity, infra-red spectroscopy, and x-ray absorption analysis. Each of these instruments will no doubt provide valuable methods in criminalistics. Let us consider, for example, the possibilities of the last mentioned technique.

The analysis of a substance by the absorption of short x-rays has only recently been made possible by the development of a photoelectric x-ray intensity meter. The sensitivity of this meter is such that differences in the absorption of x-ray energy equivalent to a ten-billionth of a watt can be measured. Thus in a pile of 100 sheets of paper, the addition or removal of a single sheet can be determined by the difference in x-ray absorption. An instrument of this nature will undoubtedly be of use in the police laboratory. Furthermore, the absorption of x-rays differs from element to element, is unaffected by the state of chemical combination of the atoms, and is independent of the physical state



of the substance. An instrument based on these principles should be of use in the physical examination and comparison of clue materials.

Broadly speaking, research in instrumentation must be viewed as an effort to provide the standard techniques and procedures necessary for an objective examination of clue materials.

### **The Collection of Statistical Data**

In Chapter 46 the application and usefulness of the mathematical concept of probability in assisting the jury to determine the innocence or guilt of a defendant was developed. It was pointed out that, in the absence of precise information concerning the frequency of occurrence of an event, it is necessary to use conservative estimates of the probability factor based on a "common sense" approach. Through research, however, it is possible to assign more correct values to the probability factors of various clue materials. For example, Kirk and Burd<sup>21</sup> have published the results of a study of the frequency of distribution of the distinguishable hues and shades of blue wool in men's suit cloths. The use of these data in the calculation of the probability of fiber matches is also discussed by these authors. Tryhorn<sup>22</sup> has also indicated the need for the compilation of statistical data, mentioning blood-and-semen stains as examples of evidence which might be enhanced in value if the frequency of occurrence was known of such stains on garments selected at random and in nowise related to crime.

### **Common Sense vs. Research**

In order to compare the calculated probability based on common sense with that based on experimental data of Kirk and Burd,<sup>23</sup> let us consider the following hypothetical case. A suspect, *X*, wearing a blue suit, is apprehended shortly after commission of an assault on *Y*, who was also wearing a blue suit. Laboratory examination of *Y*'s suit reveals it to be composed of three different shades of blue wool. In addition, it also contains several adherent fibers of two other shades of blue wool, which are found upon further examination to be the same as the shades of wool used in *X*'s suit. Furthermore *X*'s suit is also found to have adherent several blue wool fibers some of which are similar in shade to each of the three shades of wool used in *Y*'s suit. On the basis of this evidence what is the probability of *X* being the guilty party?

The probability, based on common sense might be calculated in the following manner:

Experience, i.e. common sense, tells us that there are probably about ten to twelve different shades of blue wool used in men's suits. However, since we are not certain of this, it is necessary to be conservative. Therefore, we shall assume that there are six different shades of wool, each being used with the same frequency. The probability then is  $(\frac{1}{6})^5$ ; the exponent 5 is used since there are five "unknown" fibers involved in this case. In other words, the chance of finding this combination of fibers is about 1 in every 7800 blue suits examined.

The experimental data of Kirk and Burd show that there are about 26



shades\* of distinguishable blue wools used in men's suits, each variety being found on the average of 5.88 per cent, so that the fraction  $\frac{1}{20}$  would represent the frequency of occurrence of a particular shade. The probability then is  $(\frac{1}{20})^5$  or 1 in 3,200,000 for the occurrence of the combination of fibers used in the example above.

This example illustrates how justice may frequently be frustrated by the "common sense" method, whereas, with the necessary data compiled through research, a more accurate approximation of the probability can be obtained.

### **Other Research Studies Involving Statistical Data**

Kirk and his co-workers<sup>24-29</sup> have published a series of other articles in which various physical properties such as scale count, index of refraction, specific gravity, and the like have been investigated from the standpoint of their usefulness as a means of individualization of a particular clue material. These studies may be regarded as the beginning of the vast research program that is necessary to collect the data on the frequency of occurrence and the frequency of variation of the measurable physical properties of common clue materials. The usefulness of universities offering courses in criminalistics to amass these statistical data is suggested by the fact that Professor Kirk was conducting the University of California's course in "Technical Criminology" at the time of these researches.

### **The Literature of Science**

The methods of criminalistics are in the main derived from the theories and techniques developed in other sciences. For example, spectroscopy, microscopy, photography, and serology, to name a few branches of knowledge from which forensic scientists have borrowed, were developed without any particular thought of their usefulness as a means of solving crimes. Thus, in order to cull information applicable to the work of the police laboratory, persistent study must be made of the journals of physics, chemistry, medicine, and biology. Usually, a survey of the various "abstracts" will locate the articles of likely value. The person who undertakes such a search, however, must be well acquainted with the problems of criminalistics. Articles which contain pertinent material are seldom indexed with reference to police science. Furthermore, the purpose of the authors of such pertinent articles is usually quite different from that of the criminalistician, who is largely concerned with the problem of determining whether or not two samples came from the same source. Hence, he is interested in all the techniques, instruments, and criteria which will enable him to make this determination. The men who develop the methods, instruments, and theories which may be appropriated for this purpose usually have a different objective in mind when preparing their papers. Consequently, the article is frequently entitled and indexed in a manner which is not suggestive of its value to the detective-scientist working in the police laboratory.

\* Not six (or ten to twelve) as we conservatively estimated for the calculation based on common sense.



During the preparation of this text, the authors made a brief, cursory examination of the extensive literature of the physical and biological sciences. It was found that there already exists a wealth of information which is applicable to the problems of criminalistics. However, only those theories and data which were of obvious relevancy could be considered at that time. The authors strongly feel that a thorough, extended examination of the literature of the past twenty years of science would be extremely fruitful. Thus, an extensive survey of the literature of science for the purposes of criminalistics would be a preliminary step in any large scale research program.

### 3. THE FUTURE

Homer S. Cummings, former Attorney General of the United States, has described<sup>30</sup> a case in which one Harold Israel could easily have been convicted for murder. Evidence consisting of a written confession, identification of Israel by several eyewitnesses, and an opinion by a "firearms expert" that the fatal bullet was shot from Israel's gun had been obtained by the police during the course of the investigation. In the face of this evidence the alertness displayed by the prosecutor (Mr. Cummings as Connecticut's State Attorney) in preventing a gross miscarriage of justice, has led the legal profession to regard this case as a classic illustration of the proper discharge of a prosecutor's duty — namely, protection of the innocent as well as conviction of the guilty.

While this notable example is even more impressive if one considers that it happened at a time when police laboratories were unheard of in this country, it must be remarked that today, at least in communities served by an adequately staffed, well-equipped and frequently used police laboratory, the evidence would have been viewed by the police in a different light. On the other hand, there are many communities where the services of a police laboratory are not available at the scene of a crime so that even today (unless the district attorney is as vigilant as Mr. Cummings) it is quite possible that in a similar set of circumstances the defendant would not be so fortunate.

It has been pointed out by Mr. C. M. Wilson,<sup>31</sup> Director of the Wisconsin State Police Laboratory, that courts in the future are likely to demand that evidence be examined in the laboratory when standardized procedures have been agreed upon. This situation, of course, is most desirable and will be most fruitful when the problems of basic research, instrumentation, and the collection of statistical data have been brought to a satisfactory state of completion. It will then be possible to obtain the information necessary for the jury in its deliberation of the innocence or guilt of a defendant.

It must not be thought that it is the purpose, desire, or aim of the chapter on "Proof and Probability" or of this chapter to say that it be made mandatory to use science as the only basis for solving crimes or obtaining convictions; for there will always predominate cases which are soluble without assistance from the laboratory. "Information," properly obtained, is, and will continue to be, a very valuable weapon in the armamentarium of precinct detectives and other



crime investigators. It is only when the evidence is such that a standardized examination is possible that it should be made compulsory for the evidence to be subjected to such an examination. This is desirable for it serves to protect the innocent and assists the jury in establishing guilt in an objective fashion, thereby helping to eliminate errors of human frailty. According to Borchard<sup>32</sup> there are about nine cases of unjust acquittal to one case of unjust conviction. Criminalistics is a double-edged sword that may be used to reduce both of these undesirable outcomes of judicial proceedings.

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